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HEMISPHERE SEARCH DETECTOR
Progress Report No. 9
U.S. Navy Contract No. NObsr-42179
January 31, 1949

6210096

POLAROID CORPORATION

RESEARCH DEPARTMENT

CAMBRIDGE 39, MASSACHUSETTS

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HEMISPHERE SEARCH DETECTOR

Progress Report No. 9

(Period January 4, 1949, to January 31, 1949)

Under

U.S. Navy Contract No. NObsr-42179

June 10, 1949

Polaroid Corporation

Research Department

Cambridge 39, Massachusetts

(Project RC-5)

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Progress Report No. 9

Contract No. NObsr-42179

Period January 3, 1949, to January 31, 1949

R. Clark Jones

June 10, 1949

Detailed and extensive computations have been made to determine the response of an infrared detecting system as a function of the following five quantities:

1. Effective temperature of the source
2. Spectral response of the detector
3. Meteorological conditions
4. Elevation angle of source
5. Distance of source

The results of these calculations are contained in enclosure 1 dated January 18, 1949. The results are presented in the form of 37 tables of numerical values.

Enclosure 2, dated February 24, 1949, contains brief summaries of the information available in 18 different reports on the subject of the infrared radiation from potential targets.

Enclosures 3 and 4, both dated January 7, 1949, contain detailed considerations relating to the design of the channel amplifiers used to supply the major amount of gain, and also the compression necessary to present a very large dynamic range on the screen of a cathode ray tube.

This is the last progress report on this study contract.

rcj/cbb

Report prepared by R Clark Jones
R. Clark Jones

Approved by Elkan R. Blout
Elkan R. Blout
Associate Director of Research

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Effect of Atmospheric Absorption on the Response of Infrared Detectors

Part III

R. Clark Jones

January 18, 1949

Introduction

This is the third and last of a series of three reports whose combined object is the determination of the response of an infrared detector as a function of the following five quantities:

1. Effective temperature of the source
2. Spectral response of the detector
3. Meteorological conditions
4. Elevation angle of source
5. Distance of source

In Part I, dated September 24, 1948, (plus an important supplement dated December 2, 1949) the absorption factor of the atmosphere was determined as a function of the first two of the above quantities and of the equivalent thickness of water vapor in the optical path. The results obtained in Part I were presented in Tables III, IV, and V. Each of these tables presented essentially the same information but in different forms. Table III presented the effective power in ergs per second radiated unilaterally from one square centimeter of a source at temperature T in degrees Kelvin which would be effective in evoking a response from a given detector. Table III contained the results for six detectors, six source temperatures, and six equivalent thicknesses of water vapor. Table IV showed the ratio of the response to the response that would be obtained with zero equivalent thickness of water vapor, and Table V showed the ratio of the energy utilized by a given detector to that which would be utilized by a thermocouple.

In Part II, dated November 24, 1948, the equivalent thickness of water vapor was calculated as a function of the last three quantities listed above. Part II contained no extensive numerical results, but was devoted primarily to developing the theory for the calculation of the equivalent thickness of water vapor.

In this report there is calculated the power in ergs/sec radiated by one square centimeter of the source, which is incident upon one square centimeter of receiving area and which is effective in evoking a response from the detector. The results are contained in Tables I through XXXVI. Each of these tables holds for one given source temperature and for one given detector. The power defined above is tabulated in each of the tables as a function of six different ranges, six different elevation angles, and four different surface ambient temperatures.

Theory

The present report will use essentially the theory developed in Part II but with some changes. In order to have the theory all in one place, the theory will be developed anew in this report.

Let s be the saturated density of water vapor in the atmosphere. The definition of this quantity for temperatures below 0° C is ambiguous because one does not know whether the water vapor is in equilibrium with under-cooled liquid water or with ice. This ambiguity will here be avoided by assuming that the water vapor is in equilibrium with under-cooled liquid water.

The saturated density s is a function of only the temperature. It is completely independent of the pressure. One thus has

$$s = s(t). \tag{1}$$

It will be assumed throughout this report that the temperature of the air is a function only of the elevation

$$t = t(h). \tag{2}$$

By combining these two relations one finds the density s as a function of the height

$$s = s(t(h)). \tag{3}$$

Let H be the relative humidity of the air, defined as the ratio of the actual density of water vapor to the saturated density of water vapor. It will be assumed throughout this report that the relative humidity is a function of only the elevation. One thus has

$$H = H(h). \tag{4}$$

Let u be the actual density of water vapor in the atmosphere. One then has

$$u(h) = H(h)\, s\,(t(h)). \tag{5}$$

Then, if the elevation angle of the target is θ, and if the distance to the target is R, the equivalent thickness of water vapor in the optical path, denoted by τ, is given by

$$\tau = \rho^{-1} \int_0^R u(h)\,d\ell \ , \tag{6}$$

where ℓ is the distance measured along the optical path

$$\ell = h \csc \theta. \tag{7}$$

By substituting Eqs. (5) and (7) in Eq. (6), one finds

$$\tau = \rho^{-1} \csc \theta \int_0^{R/\csc \theta} H(h)\ s\ (t(h))\ dh, \tag{8}$$

where ρ is the density of liquid water.

This expression for the equivalent thickness of water vapor in the optical path becomes determinate when one knows the functions (1), (2), and (4). In the absence of more explicit information about these functions, Eq. (8) is as far as one may go in reducing the expression to an explicit form.

Form of Equation (1)

Of the three functions to which explicit form must be given Eq. (1) is by far the most completely known. The density of water vapor in equilibrium with liquid water is given in many textbooks on thermodynamics and on steam engineering, and is given also in the Handbook of Chemistry and Physics. The information used here is taken directly from The Transmission of Infrared in Cloudy Atmosphere by H. Gaertner, Navord Report 429, dated June 1, 1947. On page 12 of this report one finds the following table:

Temperature Degrees Centigrade	Saturated Density of Water Vapor in Grams per Cubic Meter
-10	2.14
-5	3.24
0	4.84
5	6.8
10	9.4
15	12.8
20	17.3
25	23.0

This information is shown by the circles in Fig. 1 with a logarithmic scale for the density and a linear scale for the temperature. It is evident that the circles are fairly well approximated by the straight line whose formula is

$$s = s_o\, e^{\beta t} \qquad \text{(t in degrees Centigrade)} \qquad (9)$$

with

$$\begin{aligned} s_o &= 4.6\ g/m^3 \\ \beta &= 0.0665/\text{deg.} \end{aligned} \qquad (10)$$

Equations (9) and (10) provide an adequate representation for s(t) for temperatures lying between -15° C and $+30^\circ$ C. A somewhat better fit of a straight line to the data in the above table may be obtained by an expression of the form

$$s = s_o\, e^{\beta/T} \qquad \text{(T in degrees Kelvin)}$$

but the increased precision of this formula is not worth the added mathematical complexity to which it leads.

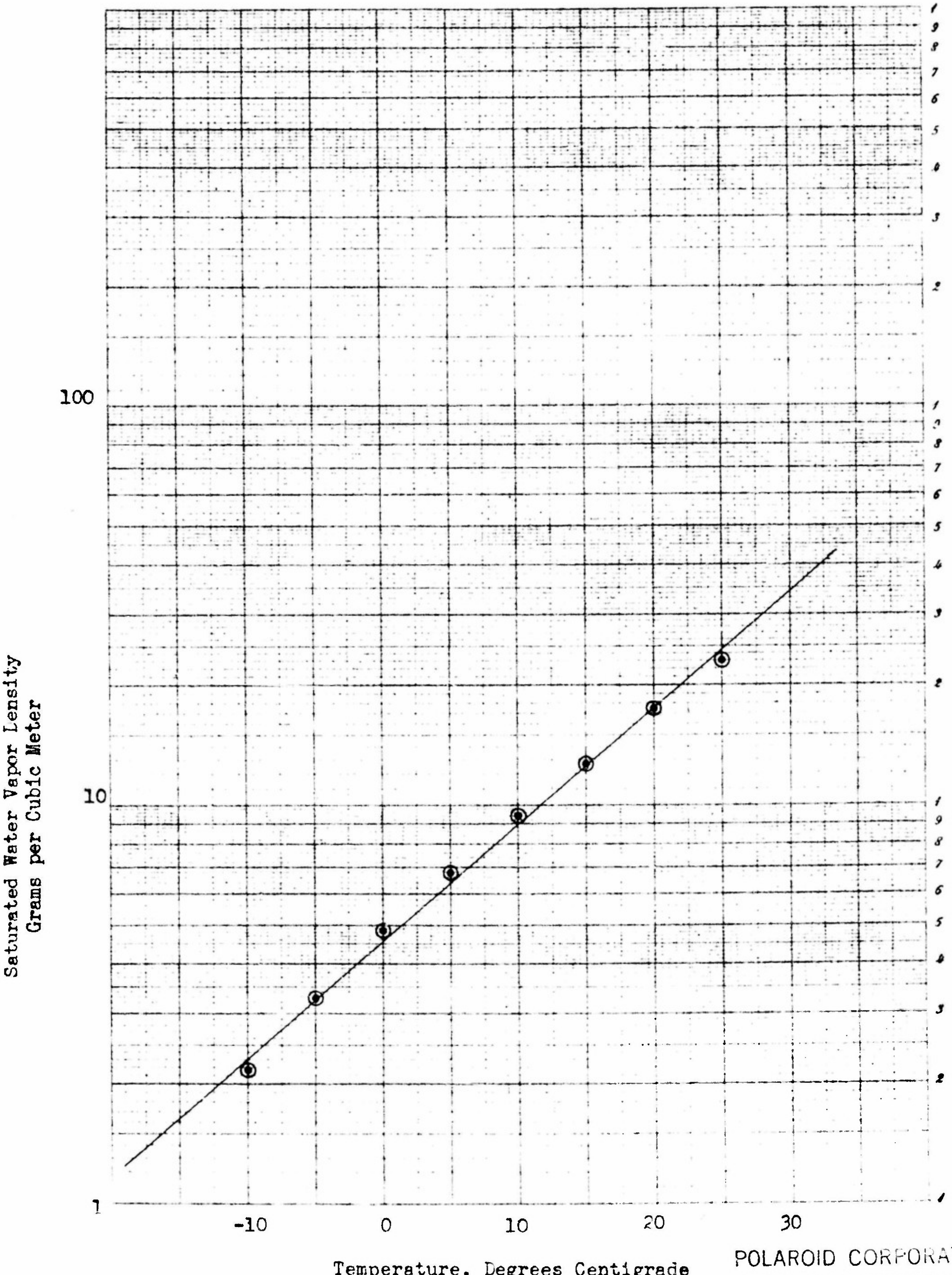
Form of Equations (2) and (4)

Unlike Eq. (1) whose form may be determined by laboratory measurements, the form of Eqs. (2) and (4) depends on meteorological conditions.

It is obvious, of course, that no simple and generally valid expressions may be written for the temperature and humidity as a function of elevation. The actual functions will depend greatly on the history of the air mass over the place in question. In particular, the presence of a front between two different air masses may lead to a very complicated situation.

It is further evident, however, that it is not feasible in these calculations to take account of all the possible conditions. Accordingly, the calculations will be based on the <u>average</u> temperature and humidity as a function of elevation.

Information on average relative humidity and average temperature as a function of elevation has been obtained from two sources.



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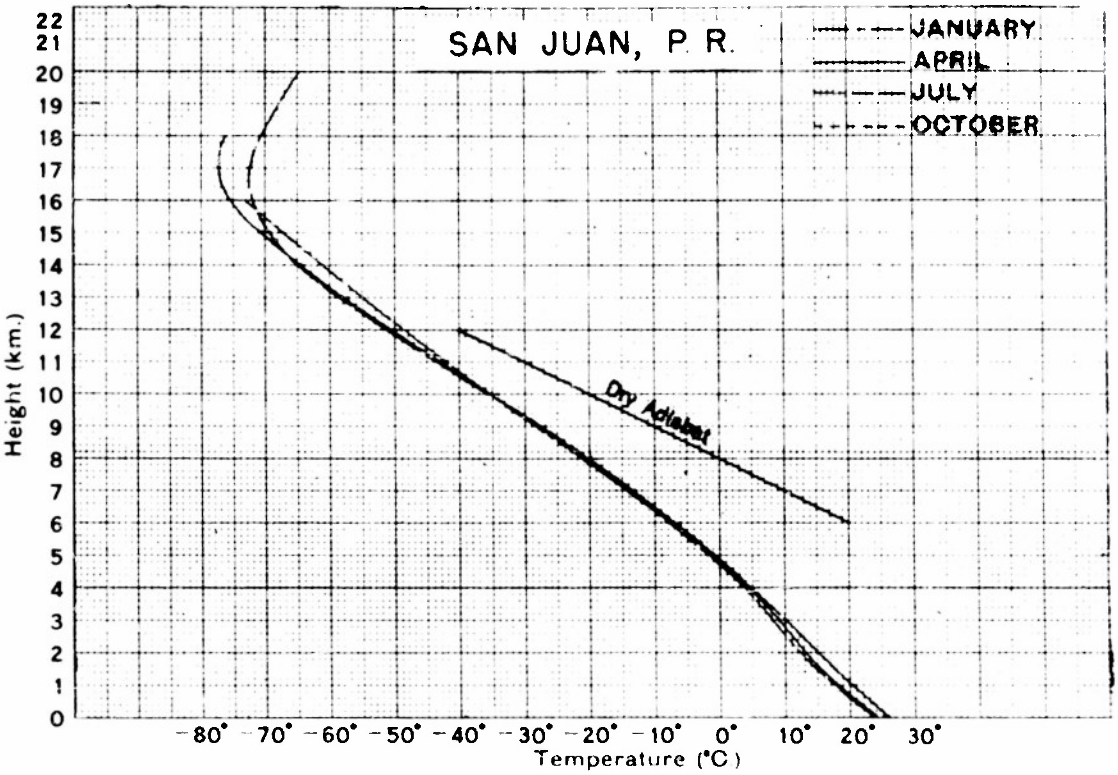
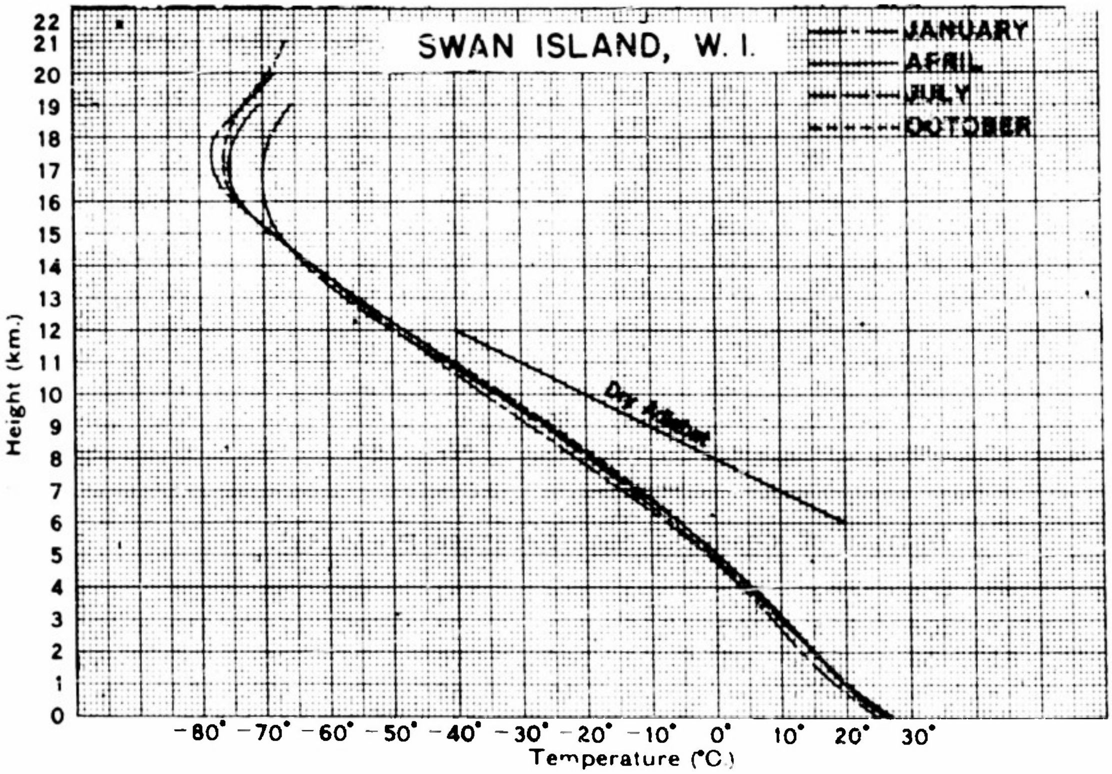
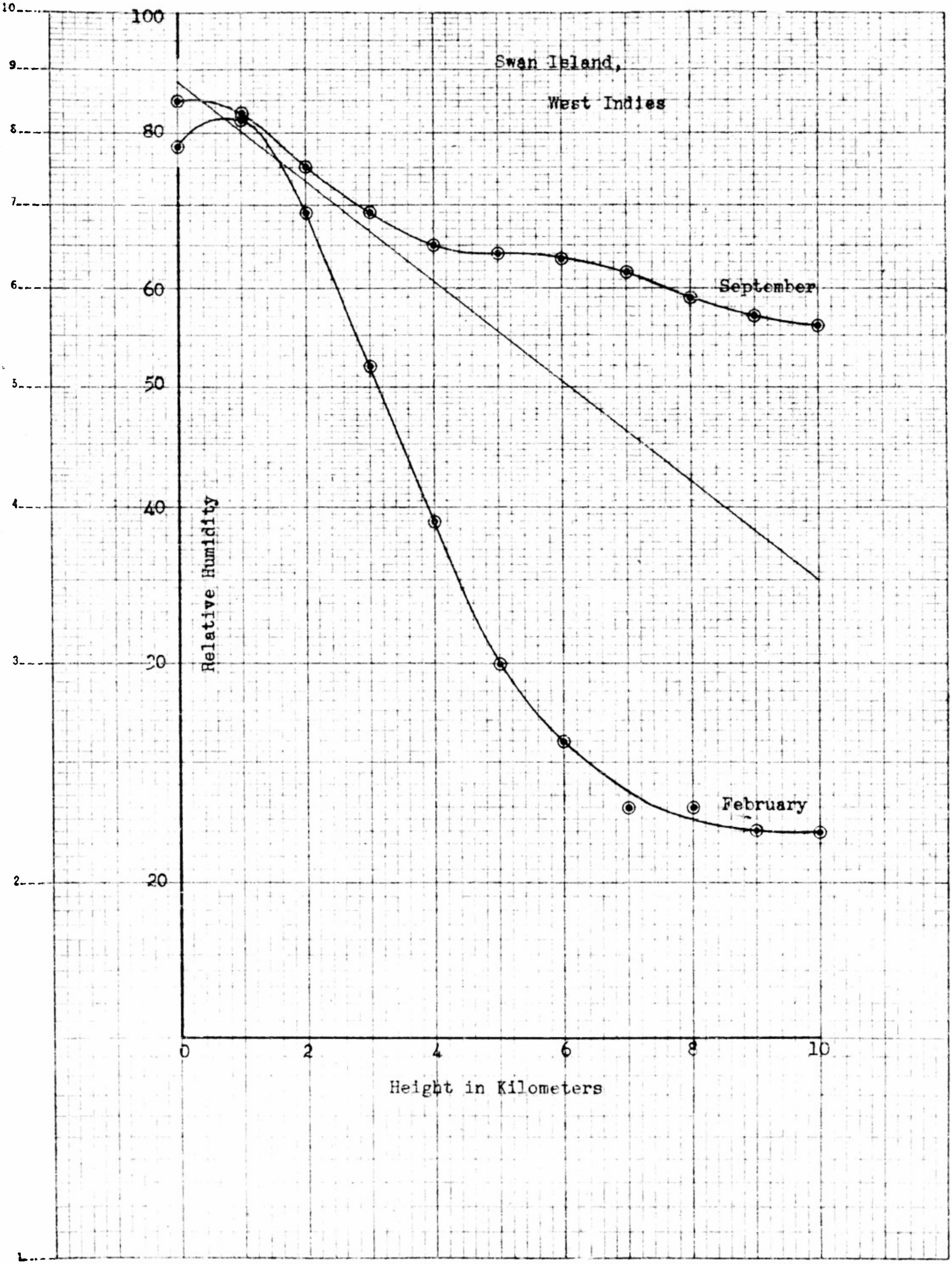


SAN JUAN, P. R.
JANUARY
APRIL
JULY
OCTOBER
Dry Adiabat
Height (km.)
Temperature (°C)



SWAN ISLAND, W. I.
JANUARY
APRIL
JULY
OCTOBER
Dry Adiabat
Height (km.)
Temperature (°C)


Swan Island,
West Indies
September
February
Relative Humidity
Height in Kilometers
100
80
60
50
40
30
20
0
2
4
6
8
10
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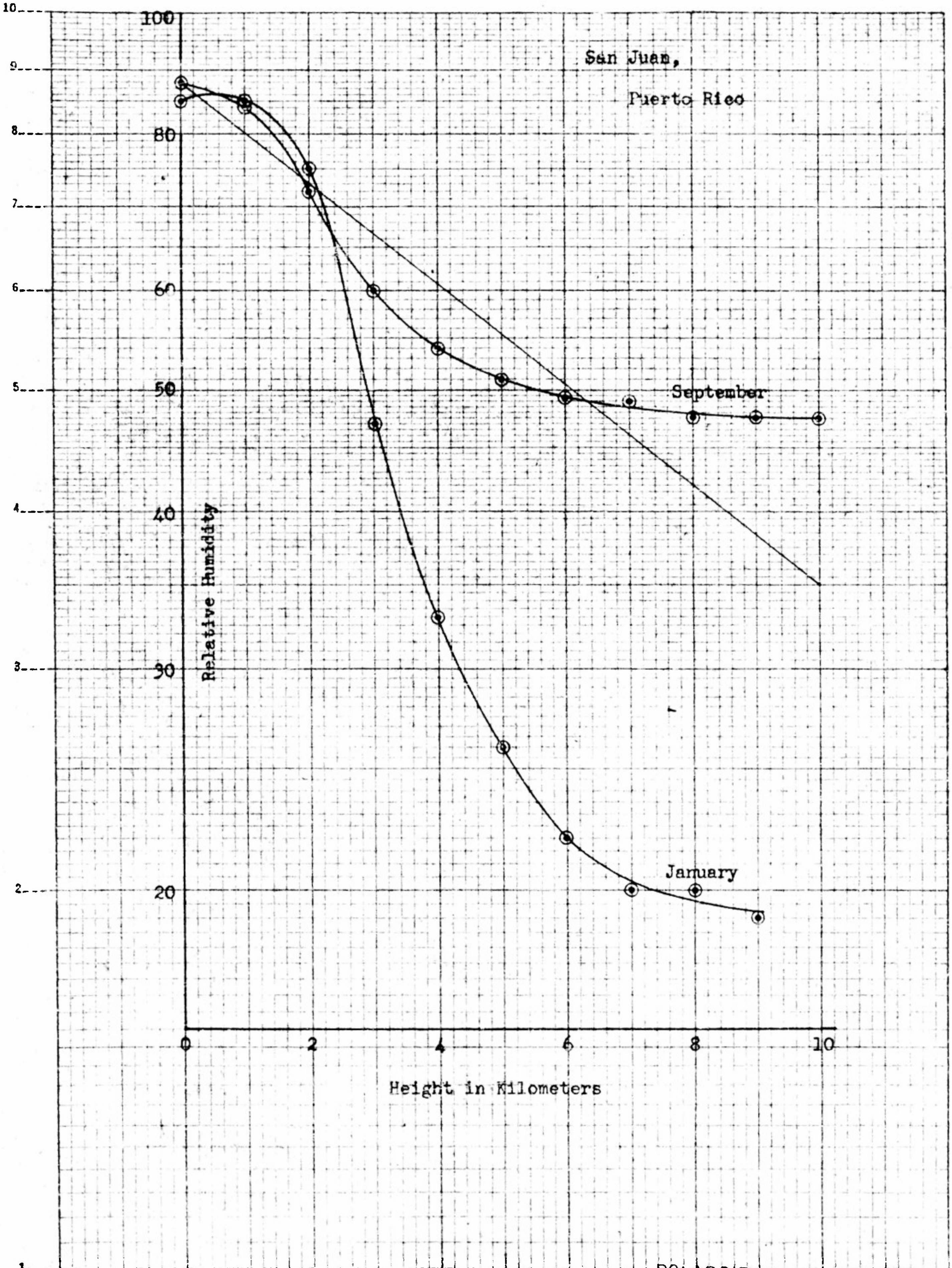

San Juan,
Puerto Rico
100
80
60
50
40
30
20
Relative Humidity
September
January
0
2
4
6
8
10
Height in Kilometers

TABLE 11.—LAPSE RATES OF TEMPERATURE IN THE LOWER TROPOSPHERE

	Latitude	Longitude	January, deg C /1000 m	July, deg C /1000 m
North America				
West Coast				
1. Nome	64°N	165°W	4.2	5.6
2. Ketchikan	55°N	132°W	5.7	5.5
3. Seattle	48°N	122°W	5.4	5.4
4. Oakland	38°N	122°W	4.9	3.4
Inland				
5. Fairbanks	65°N	148°W	3.1	7.0
6. Minneapolis	45°N	93°W	2.6	5.6
7. Oklahoma City	35°N	98°W	3.2	5.5
8. San Antonio	29°N	98°W	3.4	5.3
East Coast				
9. Portland	44°N	70°W	3.3	5.3
10. Charleston	33°N	80°W	4.1	5.7
11. Miami	26°N	80°W	4.7	5.5
Europe				
West Coast				
12. Hamburg	54°N	10°E	4.7	5.4
13. De Kooij	53°N	5°E	5.1	5.0
Inland				
14. Pavlovsk	60°N	30°E	5.0	6.0
15. Lindenberg	52°N	14°E	4.6	5.6
16. Vienna	48°N	16°E	4.3	5.4
Oceans				
17. Atlantic Station I	About 37°N	57°W	5.4	5.3
18. Atlantic Station II	About 37°N	47°W	5.6	5.0
19. Coco Solo	9°N	80°W	5.0	5.2
20. Swan Island	17°N	84°W	5.0	5.2
21. Pearl Harbor	21°N	158°W	4.5	4.8
India				
22. Agra	27°N	78°E	5.4	5.4

The first of the sources is Benjamin Ratner, "Temperature, Pressure, and Relative Humidity over the United States and Alaska" dated May, 1945. This report is available from the Climate and Crop Division of the Weather Bureau. The report contains information of the year on the temperature and relative humidity for heights between the surface and 20 kilometers. This information is given for 37 places in the United States and Alaska. The only sea locations, however, as distinct from continental locations, contained in this report are Swan Island in the West Indies and San Juan, Puerto Rico. Plots showing the vertical temperature distribution at these two locations are shown in Fig. 2. The relative humidity as a function of elevation at these two locations is plotted in Figs. 3 and 4. The two curves in each of these figures hold for the months in which the relative humidity differs most markedly. Thus the curves for all of the other months will lie between the two curves shown.

The second source of information is the book Climatology, by Bernhard Haurwitz and J. M. Austin (McGraw Hill, 1944). Pages 39-43 of this book contain an excellent discussion of the lapse rates of temperature in the troposphere. Table XI of this book is reproduced as Fig. 5. The section of the table entitled "Oceans" is of particular interest here and indicates that the lapse rates at the locations indicated are all near 5° C per kilometer in both summer and winter. This information supplements that in Fig. 2.

Examination of Figs. 2 and 5 permits the following generalization: The temperature decreases linearly as the height increases. Furthermore, in the tropical locations involved in Fig. 2, the lapse rate, and indeed the overall temperature pattern, is quite independent of the time of year.

Examination of Figs. 3 and 4 indicates that the importance of relative humidity variations is much less than that of temperature variations. Accordingly, for the purpose of a rough overall survey it is adequate to suppose that the relative humidity depends on elevation in accordance with the straight lines shown in Figs. 3 and 4. The suitability of this approximation is increased by the consideration that the relative humidity needs to be known with a fair accuracy only at small elevations. At larger elevations, the temperature is so much lower than it is at the surface, that the part of the path at higher elevations contributes only a small part of the total equivalent thickness of water vapor.

Thus it will be supposed

$$H = H_o e^{-\gamma h} \tag{11}$$

$$t = t_o - \alpha h, \tag{12}$$

where t_o and H_o are the surface temperature and the surface relative humidity, and where α and γ are constants with the dimensions of a reciprocal length. The following numerical values taken from Figs. 2, 3, 4, and 5 will be used in this report.

$$\begin{aligned} H_o &= 0.88 \\ \alpha &= 0.0051^{\circ}/\text{meter} \\ \gamma &= 0.000092/\text{meter} \\ \alpha\beta + \gamma &= 0.000436/\text{meter}. \end{aligned} \tag{13}$$

Accordingly, by virtue of the specific numerical assumptions involved in Eqs. (11), (12), and (13), the specification of the meteorological conditions has been reduced to the specification of the surface temperature t_o.

Explicit Form of Equation (8)

On the basis of Eqs. (9), (11), and (12) it is now possible to give a more explicit form to Eq. (8). Upon substituting the first three named equations in Eq. (8) and performing the indicated integrations, one finds

$$\tau = \frac{H_o s_o e^{\beta t_o} \csc\theta}{\rho(\alpha\beta + \gamma)} \left(1 - e^{-\frac{(\alpha\beta + \gamma)R}{\csc\theta}}\right). \tag{14}$$

If now one notes that the density of water vapor at the surface is given by

$$u_{surf} = s_o H_o e^{\beta t_o} \tag{15}$$

and that the water vapor density at the target is given by

$$u_{tgt} = s_o H_o e^{\beta t_o - \frac{(\alpha\beta + \gamma)R}{\csc\theta}}, \tag{16}$$

then Eq. (14) may be written in the following more compact form:

$$\tau = \frac{\csc\theta}{\rho(\alpha\beta + \gamma)} (u_{surf} - u_{tgt}). \tag{17}$$

Question of Units

It is convenient to express the saturated water vapor density u in grams per cubic meter. It is furthermore convenient to have the height h and the range expressed in meters. If then it is desired that the equivalent thickness of water vapor τ be expressed in centimeters, Eq. (17) must be written

$$\tau(R, \theta, t_o) = \frac{\csc\theta}{10^4(\alpha\beta + \gamma)} (u_{surf} - u_{tgt}), \tag{18}$$

where τ is in centimeters, u is in grams per cubic meter, α is in degrees per meter, and where the density of liquid water has been set equal to one gram per cubic centimeter.

Expression for E

Let $P(\tau, t, D)$ be the power tabulated in Table III of Part II which, as stated earlier in this report, is the power radiated unilaterally from one square centimeter of a perfectly black source whose absolute temperature is T, reduced by the transmission factor of the atmosphere containing an equivalent thickness of water vapor τ, and reduced further by a factor representing the non-uniform spectral response of the various detectors D. The last factor is unity for a thermocouple, but is less than unity for the other detectors by an amount which depends on the spectral response of the detector and the spectral composition of the radiation incident upon it. Then the energy E received upon one square centimeter located at the position of the detector which is effective in evoking a response from the detector is given by

$$E = \frac{1}{\pi R^2} P(\tau(R, \theta, t_o), T, D), \tag{19}$$

where the detector is supposed to be at the surface and the source at the position of the target.*

Equation (19) indicates that the effective energy E depends upon five quantities:

R: the distance from the target to the detector,

θ: elevation angle of the target,

t_o: the ambient temperature at the surface,

* It should be noted that the radiating area is assumed to be flat and normal to the line connecting the source and the detector. If, on the other hand, the unit area of source were a sphere of unit surface area, then an additional factor of four would appear in the denominator of the right hand side of Eq. (19).

T: the absolute temperature of the source,

D: the type of the detector.

The function $P(\tau, T, D)$ is available in tabular form in Table III of Part II, and the function $\tau(R, \theta, t_o)$ is given above in Eq. (18) by virtue of the numerical assignments (10) and (13). Accordingly, the computational basis is available for the calculation of E as a function of the five parameters.

The Computations

In accordance with the suggestions of Mr. Dauber summarized in the writer's report dated December 20, the power E has been computed for the following independent values of the five parameters:

R: 3,000; 6,000; 10,000; 20,000; and 30,000 meters

θ: 1°, 5°, 15°, 30°, 60°, and 90°

t_o: -10° C, 5° C, 20° C, and 35° C

T: 350° K, 400° K, 500° K, 600° K, 800° K, and $1{,}000^\circ$ K

D: thermocouple, PbS at 290° K, PbS at 195° K, PbS at 90° K, PbSe at 195° K, PbSe at 90° K

The above tabulation indicates that there are $5 \times 6 \times 4 \times 6 \times 6 = 4320$ different values of E to be computed.

These 4320 values of E may be tabulated in a variety of ways. The method chosen for Tables I through XXXVI is to hold the source temperature T and the type of detector D constant for each table. Thus in each table all of the values of the range R, the elevation angle θ, and the surface temperature t_o are represented. Because of the large number of results obtained it was not felt feasible to present the results in the form of plots. It may well be, however, that anyone desiring to use a restricted part of the information contained in the tables will find it desirable to construct plots for his own use.

Because of an error which became discovered only after the tables were partially typed, the quantity tabulated in the tables is not E but rather $E' = 10^4$ E. Accordingly, the quantity actually tabulated in Tables I through XXXVI may be considered as the effective power incident upon one square centimeter and radiated by one square meter of source, or conversely, as the effective power incident on one square meter and radiated by one square centimeter of source. A less useful but more symmetrical statement is that E' is the effective power incident upon one square decimeter and radiated by one square decimeter.

Method of Calculation

The method of computing the results contained in Tables I through XXXVI was as follows. In calculating τ by Eq. (18) the water vapor

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density u was plotted as a function of elevation for each of the four surface temperatures. The height of the target was computed for each of the ranges and elevation angles. The values of u_{surf} and u_{tgt} were then read off the plots and substituted in Eq. (18). The equivalent thickness of water vapor was thus determined as a function of R, θ, and and t_o.

In order to obtain E, the function P(τ,T,D), tabulated in Table III of Part II, was plotted as a function of τ for each of the 36 combinations of source temperature T and detector type D. The value of P was then read off the plots and E calculated by Eq. (19). In a few cases the value of τ computed as described in the preceding paragraph was greater than 50 cm. In these few cases, the value of E is omitted from the tables. If the value is needed, it may be obtained with fair reliability by extrapolation.

Note Added March 16

The equivalent thickness of water vapor used in calculating Tables I through XXXVI is tabulated in Table A.

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Table I

Source Temperature: 1000° K

Detector: Thermocouple

Values of $E' = 10^4$ E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.56	0.11	0.032	0.0062	0.0029
5°	0.56	0.11	0.035	0.0070	0.0033
15°	0.60	0.12	0.038	0.0088	0.0039
30°	0.64	0.13	0.046	0.011	0.0048
60°	0.67	0.15	0.053	0.013	0.0058
90°	0.67	0.16	0.055	0.014	0.0061
Surface Temperature = 20° C					
1°	0.78	0.16	0.048	0.0092	0.0035
5°	0.78	0.16	0.051	0.010	0.0039
15°	0.81	0.17	0.056	0.013	0.0055
30°	0.84	0.19	0.062	0.015	0.0067
60°	0.88	0.20	0.071	0.018	0.0079
90°	0.92	0.21	0.075	0.019	0.0082
Surface Temperature = 5° C					
1°	1.0	0.21	0.064	0.013	0.0051
5°	1.0	0.21	0.067	0.014	0.0060
15°	1.1	0.23	0.075	0.018	0.0074
30°	1.1	0.25	0.086	0.021	0.0092
60°	1.2	0.27	0.099	0.024	0.011
90°	1.2	0.28	0.10	0.025	0.011
Surface Temperature = -10° C					
1°	1.2	0.28	0.089	0.018	0.0071
5°	1.2	0.29	0.092	0.020	0.0081
15°	1.2	0.30	0.10	0.023	0.010
30°	1.2	0.30	0.11	0.027	0.012
60°	1.2	0.30	0.11	0.027	0.012
90°	1.2	0.30	0.11	0.027	0.012

Table II

Source Temperature: 800° K

Detector: Thermocouple

Values of $E' = 10^4 E$, where E is in ergs/(sec-cm^4)

	Range in Meters				
	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.19	0.040	0.013	0.0027	0.0012
5°	0.19	0.040	0.013	0.0029	0.0013
15°	0.20	0.042	0.014	0.0032	0.0014
30°	0.21	0.044	0.015	0.0036	0.0016
60°	0.23	0.050	0.017	0.0044	0.0019
90°	0.23	0.053	0.018	0.0045	0.0020
Surface Temperature = 20° C					
1°	0.27	0.053	0.016	0.0033	0.0014
5°	0.28	0.053	0.017	0.0036	0.0015
15°	0.30	0.058	0.018	0.0042	0.0018
30°	0.31	0.065	0.022	0.0052	0.0023
60°	0.33	0.075	0.026	0.0065	0.0029
90°	0.35	0.080	0.028	0.0070	0.0031
Surface Temperature = 5° C					
1°	0.37	0.080	0.023	0.0044	0.0013
5°	0.37	0.080	0.024	0.0049	0.0019
15°	0.39	0.087	0.028	0.0065	0.0027
30°	0.41	0.089	0.031	0.0072	0.0034
60°	0.42	0.10	0.035	0.0083	0.0039
90°	0.42	0.11	0.035	0.0083	0.0039
Surface Temperature = -10° C					
1°	0.49	0.10	0.032	0.0066	0.0025
5°	0.49	0.11	0.032	0.0071	0.0030
15°	0.49	0.11	0.035	0.0080	0.0035
30°	0.53	0.12	0.041	0.0095	0.0042
60°	0.53	0.12	0.044	0.011	0.0050
90°	0.53	0.13	0.044	0.011	0.0050

Table III

Source Temperature: 600° K

Detector: Thermocouple

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.039	0.0066	0.0018	------	------
5°	0.039	0.0066	0.0020	0.00043	------
15°	0.042	0.0074	0.0022	0.00049	0.00021
30°	0.042	0.0084	0.0027	0.00065	0.00028
60°	0.046	0.011	0.0035	0.00087	0.00039
90°	0.049	0.011	0.0038	0.00095	0.00042
Surface Temperature = 20° C					
1°	0.061	0.012	0.0029	0.00052	0.00020
5°	0.064	0.012	0.0031	0.00060	0.00024
15°	0.067	0.013	0.0038	0.00080	0.00034
30°	0.071	0.014	0.0047	0.0011	0.00049
60°	0.078	0.017	0.0057	0.0014	0.00063
90°	0.081	0.019	0.0063	0.0015	0.00067
Surface Temperature = 5° C					
1°	0.10	0.018	0.0047	0.00087	0.00031
5°	0.10	0.019	0.0054	0.0010	0.00039
15°	0.11	0.020	0.0063	0.0014	0.00060
30°	0.12	0.024	0.0076	0.0018	0.00077
60°	0.13	0.027	0.0098	0.0025	0.0011
90°	0.13	0.029	0.010	0.0025	0.0011
Surface Temperature = -10° C					
1°	0.14	0.027	0.0083	0.0014	0.00053
5°	0.14	0.029	0.0089	0.0017	0.00067
15°	0.14	0.033	0.010	0.0024	0.00099
30°	0.15	0.035	0.012	0.0029	0.0013
60°	0.15	0.037	0.013	0.0032	0.0014
90°	0.15	0.037	0.013	0.0033	0.0015

Table IV

Source Temperature 500° K

Detector: Thermocouple

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

	Range in Meters				
	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.012	0.0020	0.00057	------	------
5°	0.012	0.0020	0.00060	0.00012	------
15°	0.013	0.0023	0.00070	0.00019	0.000063
30°	0.014	0.0027	0.00076	0.00020	0.000088
60°	0.016	0.0033	0.0011	0.00028	0.00012
90°	0.017	0.0035	0.0012	0.00030	0.00013
Surface Temperature = 20° C					
1°	0.023	0.0036	0.00092	0.00016	0.000060
5°	0.024	0.0036	0.0010	0.00018	0.000071
15°	0.025	0.0039	0.0012	0.00025	0.00011
30°	0.028	0.0052	0.0016	0.00038	0.00017
60°	0.033	0.0067	0.0022	0.00056	0.00025
90°	0.035	0.0073	0.0025	0.00061	0.00027
Surface Temperature = 5° C					
1°	0.046	0.0073	0.0018	0.00028	0.000099
5°	0.046	0.0075	0.0019	0.00037	0.00013
15°	0.049	0.0090	0.0025	0.00051	0.00022
30°	0.053	0.011	0.0035	0.00078	0.00034
60°	0.056	0.012	0.0041	0.0010	0.00046
90°	0.056	0.013	0.0045	0.0011	0.00049
Surface Temperature = -10° C					
1°	0.060	0.012	0.0038	0.00056	0.00018
5°	0.060	0.013	0.0038	0.00070	0.00025
15°	0.064	0.014	0.0045	0.0010	0.00042
30°	0.065	0.015	0.0051	0.0013	0.00056
60°	0.067	0.016	0.0057	0.0014	0.00063
90°	0.067	0.016	0.0059	0.0015	0.00065

Table V

Source Temperature: 400° K

Detector: Thermocouple

Values of $E' = 10^4 E$, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.0021	0.00032	0.000083	------	------
5°	0.0021	0.00032	0.000089	0.000017	------
15°	0.0023	0.00037	0.00010	0.000022	0.0000095
30°	0.0026	0.00045	0.00014	0.000032	0.000014
60°	0.0032	0.00061	0.00020	0.000050	0.000022
90°	0.0035	0.00068	0.00023	0.000056	0.000025
Surface Temperature = 20° C					
1°	0.0053	0.00069	0.00015	0.000024	0.0000088
5°	0.0056	0.00070	0.00018	0.000029	0.000011
15°	0.0064	0.0011	0.00023	0.000045	0.000018
30°	0.0074	0.0012	0.00035	0.000078	0.000033
60°	0.0094	0.0018	0.00054	0.00014	0.000060
90°	0.0099	0.0020	0.00066	0.00016	0.000070
Surface Temperature = 5° C					
1°	0.012	0.0020	0.00038	0.000048	0.000016
5°	0.013	0.0020	0.00045	0.000066	0.000023
15°	0.014	0.0025	0.00066	0.00012	0.000049
30°	0.015	0.0031	0.00095	0.00022	0.000095
60°	0.016	0.0036	0.0013	0.00031	0.00014
90°	0.016	0.0038	0.0014	0.00033	0.00015
Surface Temperature = -10° C					
1°	0.017	0.0036	0.0011	0.00014	0.000039
5°	0.017	0.0038	0.0012	0.00019	0.000064
15°	0.018	0.0041	0.0014	0.00029	0.00013
30°	0.018	0.0042	0.0015	0.00037	0.00016
60°	0.018	0.0044	0.0016	0.00039	0.00017
90°	0.018	0.0044	0.0016	0.00040	0.00017

Table VI

Source Temperature: 350° K

Detector: Thermocouple

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.00057	0.000069	0.000019	------	------
5°	0.00057	0.000069	0.000021	0.0000032	------
15°	0.00064	0.000099	0.000022	0.0000051	0.0000021
30°	0.00074	0.00012	0.000035	0.0000080	0.0000035
60°	0.00095	0.00018	0.000057	0.000013	0.0000060
90°	0.0010	0.00019	0.000064	0.000016	0.0000071
Surface Temperature = 20° C					
1°	0.0017	0.00020	0.000041	0.0000055	0.0000021
5°	0.0019	0.00020	0.000048	0.0000070	0.0000032
15°	0.0021	0.00027	0.000067	0.000012	0.0000049
30°	0.0026	0.00037	0.00010	0.000023	0.0000099
60°	0.0035	0.00059	0.00019	0.000045	0.000020
90°	0.0039	0.00070	0.00021	0.000055	0.000025
Surface Temperature = 5° C					
1°	0.0053	0.00069	0.00012	0.000013	0.0000033
5°	0.0053	0.00073	0.00014	0.000019	0.0000060
15°	0.0057	0.00099	0.00023	0.000048	0.000016
30°	0.0062	0.0012	0.00038	0.000087	0.000035
60°	0.0067	0.0015	0.00051	0.00013	0.000056
90°	0.0067	0.0016	0.00054	0.00013	0.000060
Surface Temperature = -10° C					
1°	0.0074	0.0015	0.00044	0.000045	0.000012
5°	0.0074	0.0016	0.00048	0.000067	0.000021
15°	0.0074	0.0017	0.00054	0.00012	0.000049
30°	0.0078	0.0019	0.00064	0.00015	0.000067
60°	0.0078	0.0019	0.00067	0.00017	0.000074
90°	0.0078	0.0019	0.00070	0.00018	0.000078

Table VII

Source Temperature: 1000° K

Detector: PbS, 290° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.18	0.040	0.013	------	------
5°	0.18	0.040	0.013	0.0028	------
15°	0.19	0.041	0.014	0.0033	0.0015
30°	0.19	0.043	0.015	0.0036	0.0016
60°	0.20	0.046	0.016	0.0040	0.0018
90°	0.20	0.047	0.017	0.0041	0.0018
Surface Temperature = 20° C					
1°	0.22	0.047	0.015	0.0034	0.0015
5°	0.23	0.048	0.016	0.0036	0.0015
15°	0.23	0.050	0.017	0.0040	0.0017
30°	0.24	0.053	0.018	0.0045	0.0020
60°	0.26	0.058	0.020	0.0050	0.0022
90°	0.26	0.059	0.021	0.0052	0.0023
Surface Temperature = 5° C					
1°	0.29	0.059	0.019	0.0041	0.0017
5°	0.29	0.060	0.019	0.0043	0.0018
15°	0.31	0.064	0.021	0.0049	0.0022
30°	0.32	0.070	0.024	0.0057	0.0026
60°	0.34	0.077	0.027	0.0067	0.0029
90°	0.34	0.080	0.028	0.0070	0.0031
Surface Temperature = -10° C					
1°	0.35	0.077	0.025	0.0051	0.0020
5°	0.35	0.079	0.025	0.0055	0.0022
15°	0.37	0.084	0.028	0.0065	0.0028
30°	0.39	0.089	0.031	0.0075	0.0033
60°	0.39	0.093	0.033	0.0083	0.0037
90°	0.39	0.097	0.035	0.0087	0.0039

Table VIII

Source Temperature: 800° K

Detector: PbS, 290° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.033	0.0073	0.0023	------	------
5°	0.033	0.0073	0.0024	0.00049	------
15°	0.033	0.0076	0.0025	0.00061	0.00026
30°	0.034	0.0080	0.0028	0.00068	0.00030
60°	0.035	0.0084	0.0030	0.00075	0.00033
90°	0.035	0.0085	0.0030	0.00076	0.00034
Surface Temperature = 20° C					
1°	0.039	0.0086	0.0028	0.00060	0.00025
5°	0.039	0.0086	0.0029	0.00065	0.00027
15°	0.039	0.0087	0.0030	0.00073	0.00032
30°	0.039	0.0094	0.0032	0.00079	0.00035
60°	0.042	0.0098	0.0035	0.00087	0.00039
90°	0.042	0.0098	0.0035	0.00087	0.00039
Surface Temperature = 5° C					
1°	0.046	0.011	0.0032	0.00074	0.00031
5°	0.049	0.011	0.0033	0.00078	0.00033
15°	0.056	0.011	0.0035	0.00083	0.00037
30°	0.056	0.012	0.0038	0.00095	0.00042
60°	0.063	0.014	0.0048	0.0012	0.00053
90°	0.063	0.015	0.0054	0.0013	0.00056
Surface Temperature = -10° C					
1°	0.070	0.014	0.0042	0.00087	0.00035
5°	0.070	0.015	0.0044	0.00095	0.00039
15°	0.074	0.016	0.0051	0.0011	0.00049
30°	0.076	0.018	0.0061	0.0014	0.00063
60°	0.078	0.019	0.0067	0.0017	0.00074
90°	0.081	0.019	0.0067	0.0017	0.00074

Table IX

Source Temperature 600° K

Detector: PbS, 290° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000	
Surface Temperature = 35° C						
1°	0.0024	0.00049	0.00013	------	------	
5°	0.0024	0.00049	0.00015	0.000025	------	
15°	0.0025	0.00053	0.00017	0.000037	0.000016	
30°	0.0026	0.00057	0.00019	0.000047	0.000021	
60°	0.0027	0.00064	0.00022	0.000056	0.000025	
90°	0.0028	0.00065	0.00023	0.000058	0.000026	
Surface Temperature = 20° C						
1°	0.0030	0.00065	0.00020	0.000039	0.000015	
5°	0.0031	0.00066	0.00021	0.000044	0.000018	5
15°	0.0032	0.00070	0.00023	0.000054	0.000023	
30°	0.0033	0.00075	0.00026	0.000062	0.000027	
60°	0.0035	0.00081	0.00029	0.000071	0.000032	6
90°	0.0035	0.00085	0.00030	0.000074	0.000033	
Surface Temperature = 5° C						
1°	0.0040	0.00084	0.00026	0.000056	0.000022	
5°	0.0042	0.00085	0.00027	0.000060	0.000025	
15°	0.0046	0.00089	0.00030	0.000069	0.000030	
30°	0.0049	0.0011	0.00035	0.000080	0.000035	
60°	0.0053	0.0012	0.00041	0.00010	0.000046	
90°	0.0056	0.0012	0.00045	0.00011	0.000049	
Surface Temperature = −10° C						
1°	0.0060	0.0012	0.00037	0.000071	0.000029	
5°	0.0062	0.0012	0.00038	0.000078	0.000032	
15°	0.0065	0.0014	0.00045	0.000095	0.000042	
30°	0.0067	0.0016	0.00051	0.00012	0.000053	
60°	0.0070	0.0017	0.00057	0.00014	0.000064	
90°	0.0070	0.0017	0.00060	0.00015	0.000067	

Table X

Source Temperature 500° K

Detector: PbS, 290° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.00032	0.000059	0.000016	--------	--------
5°	0.00032	0.000059	0.000017	0.0000033	--------
15°	0.00034	0.000065	0.000020	0.0000044	0.0000019
30°	0.00035	0.000073	0.000024	0.0000057	0.0000025
60°	0.00035	0.000087	0.000030	0.0000075	0.0000033
90°	0.00035	0.000090	0.000032	0.0000080	0.0000035
Surface Temperature = 20° C					
1°	0.00039	0.000083	0.000026	0.0000051	0.0000018
5°	0.00039	0.000085	0.000027	0.0000057	0.0000023
15°	0.00039	0.000090	0.000030	0.0000071	0.0000031
30°	0.00039	0.000093	0.000032	0.0000080	0.0000035
60°	0.00042	0.000097	0.000035	0.0000088	0.0000039
90°	0.00046	0.000097	0.000035	0.0000088	0.0000039
Surface Temperature = 5° C					
1°	0.00060	0.000097	0.000032	0.0000073	0.0000031
5°	0.00064	0.00010	0.000033	0.0000078	0.0000033
15°	0.00067	0.00011	0.000035	0.0000088	0.0000038
30°	0.00071	0.00013	0.000041	0.0000095	0.0000042
60°	0.00078	0.00017	0.000057	0.000014	0.0000064
90°	0.00078	0.00018	0.000060	0.000015	0.0000066
Surface Temperature = -10° C					
1°	0.00084	0.00017	0.000048	0.0000088	0.0000035
5°	0.00088	0.00018	0.000051	0.0000095	0.0000039
15°	0.00092	0.00019	0.000060	0.000013	0.0000053
30°	0.00092	0.00021	0.000073	0.000017	0.0000078
60°	0.00095	0.00023	0.000083	0.000021	0.0000092
90°	0.00099	0.00024	0.000083	0.000021	0.0000092

Table XI

Source Temperature 400° K

Detector: PbS, 290° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.000015	0.0000032	8.3×10^{-7}	--------	--------
5°	0.000015	0.0000032	9.2×10^{-7}	1.4×10^{-7}	--------
15°	0.000015	0.0000034	1.1×10^{-6}	2.4×10^{-7}	9.9×10^{-8}
30°	0.000016	0.0000036	1.3×10^{-6}	3.0×10^{-7}	1.3×10^{-7}
60°	0.000016	0.0000038	1.4×10^{-6}	3.4×10^{-7}	1.5×10^{-7}
90°	0.000016	0.0000038	1.4×10^{-6}	3.4×10^{-7}	1.5×10^{-7}
Surface Temperature = 20° C					
1°	0.000017	0.0000040	1.3×10^{-6}	2.5×10^{-7}	8.8×10^{-8}
5°	0.000017	0.0000040	1.3×10^{-6}	2.9×10^{-7}	1.1×10^{-7}
15°	0.000018	0.0000040	1.4×10^{-6}	3.3×10^{-7}	1.5×10^{-7}
30°	0.000018	0.0000042	1.4×10^{-6}	3.6×10^{-7}	1.6×10^{-7}
60°	0.000019	0.0000044	1.6×10^{-6}	3.9×10^{-7}	1.7×10^{-7}
90°	0.000019	0.0000046	1.6×10^{-6}	4.0×10^{-7}	1.8×10^{-7}
Surface Temperature = 5° C					
1°	0.000029	0.0000046	1.5×10^{-6}	3.4×10^{-7}	1.4×10^{-7}
5°	0.000029	0.0000046	1.5×10^{-6}	3.6×10^{-7}	1.5×10^{-7}
15°	0.000033	0.0000050	1.6×10^{-6}	3.8×10^{-7}	1.7×10^{-7}
30°	0.000037	0.0000064	1.9×10^{-6}	4.5×10^{-7}	2.0×10^{-7}
60°	0.000049	0.0000089	2.9×10^{-6}	7.2×10^{-7}	3.2×10^{-7}
90°	0.000051	0.0000098	3.2×10^{-6}	8.0×10^{-7}	3.5×10^{-7}
Surface Temperature = -10° C					
1°	0.000055	0.0000089	2.2×10^{-6}	3.9×10^{-7}	1.6×10^{-7}
5°	0.000055	0.0000098	2.4×10^{-6}	4.3×10^{-7}	1.7×10^{-7}
15°	0.000058	0.000012	3.3×10^{-6}	6.4×10^{-7}	2.6×10^{-7}
30°	0.000060	0.000013	4.4×10^{-6}	1.1×10^{-6}	4.9×10^{-7}
60°	0.000063	0.000015	5.2×10^{-6}	1.3×10^{-6}	5.8×10^{-7}
90°	0.000065	0.000015	5.4×10^{-6}	1.4×10^{-6}	6.0×10^{-7}

Table XII

Source Temperature 350° K

Detector: PbS, 290° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	1.6×10^{-6}	3.1×10^{-7}	8.6×10^{-8}	--------	--------
5°	1.6×10^{-6}	3.1×10^{-7}	9.7×10^{-8}	1.2×10^{-8}	--------
15°	1.6×10^{-6}	3.3×10^{-7}	1.0×10^{-7}	2.2×10^{-8}	9.2×10^{-9}
30°	1.6×10^{-6}	3.7×10^{-7}	1.2×10^{-7}	3.0×10^{-8}	1.3×10^{-8}
60°	1.7×10^{-6}	4.1×10^{-7}	1.5×10^{-7}	3.6×10^{-8}	1.6×10^{-8}
90°	1.7×10^{-6}	4.2×10^{-7}	1.5×10^{-7}	3.7×10^{-8}	1.6×10^{-8}
Surface Temperature = 20° C					
1°	1.7×10^{-6}	4.2×10^{-7}	1.3×10^{-7}	2.4×10^{-8}	8.1×10^{-9}
5°	1.7×10^{-6}	4.2×10^{-7}	1.4×10^{-7}	2.9×10^{-8}	1.1×10^{-8}
15°	1.8×10^{-6}	4.3×10^{-7}	1.5×10^{-7}	3.5×10^{-8}	1.5×10^{-8}
30°	1.8×10^{-6}	4.3×10^{-7}	1.5×10^{-7}	3.7×10^{-8}	1.7×10^{-8}
60°	1.8×10^{-6}	4.4×10^{-7}	1.6×10^{-7}	4.0×10^{-8}	1.8×10^{-8}
90°	1.8×10^{-6}	4.4×10^{-7}	1.6×10^{-7}	4.0×10^{-8}	1.8×10^{-8}
Surface Temperature = 5° C					
1°	3.1×10^{-6}	4.3×10^{-7}	1.5×10^{-7}	3.6×10^{-8}	1.4×10^{-8}
5°	3.2×10^{-6}	4.4×10^{-7}	1.5×10^{-7}	3.7×10^{-8}	1.6×10^{-8}
15°	3.5×10^{-6}	4.7×10^{-7}	1.6×10^{-7}	3.9×10^{-8}	1.7×10^{-8}
30°	3.7×10^{-6}	6.3×10^{-7}	1.7×10^{-7}	4.1×10^{-8}	1.8×10^{-8}
60°	4.9×10^{-6}	9.7×10^{-7}	3.1×10^{-7}	7.8×10^{-8}	3.5×10^{-8}
90°	5.1×10^{-6}	1.1×10^{-6}	3.9×10^{-7}	8.8×10^{-8}	3.9×10^{-8}
Surface Temperature = -10° C					
1°	6.0×10^{-6}	9.0×10^{-7}	2.2×10^{-7}	4.0×10^{-8}	1.7×10^{-8}
5°	6.3×10^{-6}	1.1×10^{-6}	2.5×10^{-7}	4.0×10^{-8}	1.7×10^{-8}
15°	6.7×10^{-6}	1.3×10^{-6}	3.8×10^{-7}	6.9×10^{-8}	2.8×10^{-8}
30°	7.2×10^{-6}	1.5×10^{-6}	5.4×10^{-7}	1.1×10^{-7}	5.1×10^{-8}
60°	7.8×10^{-6}	1.8×10^{-6}	6.8×10^{-7}	1.5×10^{-7}	6.7×10^{-8}
90°	8.1×10^{-6}	1.9×10^{-6}	7.1×10^{-7}	1.6×10^{-7}	7.1×10^{-8}

Table XIII

Source Temperature: 1000° K

Detector: PbS, 195° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.23	0.049	0.014	------	------
5°	0.23	0.049	0.015	0.0028	------
15°	0.23	0.051	0.017	0.0037	0.0016
30°	0.23	0.055	0.019	0.0045	0.0020
60°	0.24	0.057	0.020	0.0051	0.0023
90°	0.24	0.058	0.021	0.0052	0.0023
Surface Temperature = 20° C					
1°	0.25	0.059	0.019	0.0039	0.0014
5°	0.25	0.059	0.020	0.0044	0.0018
15°	0.25	0.060	0.021	0.0048	0.0021
30°	0.26	0.062	0.022	0.0054	0.0024
60°	0.28	0.065	0.023	0.0057	0.0025
90°	0.29	0.067	0.024	0.0059	0.0026
Surface Temperature = 5° C					
1°	0.37	0.067	0.022	0.0051	0.0021
5°	0.37	0.067	0.022	0.0053	0.0023
15°	0.39	0.073	0.024	0.0056	0.0025
30°	0.42	0.085	0.027	0.0064	0.0029
60°	0.46	0.10	0.035	0.0087	0.0039
90°	0.48	0.11	0.038	0.0095	0.0042
Surface Temperature = -10° C					
1°	0.51	0.10	0.029	0.0057	0.0025
5°	0.51	0.11	0.032	0.0062	0.0025
15°	0.53	0.12	0.038	0.0080	0.0035
30°	0.55	0.13	0.040	0.010	0.0046
60°	0.56	0.13	0.048	0.012	0.0053
90°	0.56	0.14	0.049	0.012	0.0055

Table XIV

Source Temperature: 800° K

Detector: PbS, 195° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.046	0.0098	0.0027	--------	--------
5°	0.046	0.0098	0.0029	0.00057	--------
15°	0.046	0.010	0.0032	0.00073	0.00032
30°	0.048	0.011	0.0037	0.00088	0.00039
60°	0.049	0.012	0.0041	0.0010	0.00046
90°	0.049	0.012	0.0041	0.0010	0.00046
Surface Temperature = 20° C					
1°	0.053	0.012	0.0038	0.00076	0.00029
5°	0.053	0.012	0.0040	0.00088	0.00035
15°	0.053	0.012	0.0041	0.0010	0.00042
30°	0.055	0.013	0.0044	0.0011	0.00049
60°	0.056	0.013	0.0048	0.0012	0.00053
90°	0.058	0.014	0.0048	0.0012	0.00053
Surface Temperature = 5° C					
1°	0.072	0.012	0.0046	0.0010	0.00042
5°	0.074	0.014	0.0048	0.0011	0.00046
15°	0.085	0.015	0.0049	0.0012	0.00053
30°	0.092	0.018	0.0056	0.0013	0.00058
60°	0.10	0.022	0.0075	0.0018	0.00081
90°	0.11	0.024	0.0083	0.0021	0.00092
Surface Temperature = -10° C					
1°	0.12	0.022	0.0060	0.0012	0.00051
5°	0.12	0.024	0.0067	0.0013	0.00053
15°	0.12	0.026	0.0083	0.0017	0.00072
30°	0.13	0.029	0.0099	0.0024	0.0011
60°	0.13	0.031	0.011	0.0028	0.0012
90°	0.13	0.032	0.011	0.0029	0.0013

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Table XV

Source Temperature: 600° K

Detector: PbS, 195° K

Values of $E' = 10^4$ E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.0028	0.00053	0.00014	--------	--------
5°	0.0028	0.00053	0.00015	0.000028	--------
15°	0.0028	0.00058	0.00018	0.000039	0.000017
30°	0.0030	0.00065	0.00021	0.000051	0.000023
60°	0.0031	0.00073	0.00025	0.000064	0.000028
90°	0.0031	0.00075	0.00026	0.000066	0.000029
Surface Temperature = 20° C					
1°	0.0033	0.00074	0.00022	0.000041	0.000015
5°	0.0033	0.00074	0.00024	0.000048	0.000019
15°	0.0033	0.00077	0.00026	0.000060	0.000026
30°	0.0034	0.00080	0.00028	0.000070	0.000031
60°	0.0035	0.00084	0.00030	0.000074	0.000033
90°	0.0035	0.00088	0.00031	0.000077	0.000034
Surface Temperature = 5° C					
1°	0.0060	0.00087	0.00029	0.000063	0.000024
5°	0.0060	0.00087	0.00029	0.000068	0.000029
15°	0.0063	0.00094	0.00031	0.000073	0.000032
30°	0.0071	0.0012	0.00035	0.000080	0.000035
60°	0.0081	0.0017	0.00057	0.00014	0.000060
90°	0.0083	0.0018	0.00060	0.00015	0.000064
Surface Temperature = -10° C					
1°	0.0095	0.0017	0.00041	0.000074	0.000031
5°	0.0095	0.0018	0.00048	0.000078	0.000032
15°	0.010	0.0021	0.00063	0.00012	0.000050
30°	0.011	0.0023	0.00078	0.00018	0.000083
60°	0.011	0.0026	0.00090	0.00021	0.000099
90°	0.011	0.0027	0.00092	0.00023	0.00010

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Table XVI

Source Temperature: 500° K

Detector: PbS, 195° K

Values of $E' = 10^4 E$, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.00035	0.000066	0.000019	--------	--------
5°	0.00035	0.000066	0.000020	0.0000037	--------
15°	0.00035	0.000072	0.000022	0.0000050	0.0000022
30°	0.00037	0.000080	0.000027	0.0000064	0.0000028
60°	0.00039	0.000089	0.000032	0.0000079	0.0000035
90°	0.00041	0.000093	0.000033	0.0000080	0.0000035
Surface Temperature = 20° C					
1°	0.00046	0.000097	0.000031	0.0000052	0.0000020
5°	0.00046	0.000097	0.000030	0.0000060	0.0000024
15°	0.00046	0.00010	0.000033	0.0000075	0.0000033
30°	0.00048	0.00011	0.000036	0.0000088	0.0000039
60°	0.00049	0.00011	0.000041	0.000010	0.0000046
90°	0.00049	0.00012	0.000041	0.000010	0.0000046
Surface Temperature = 5° C					
1°	0.00071	0.00011	0.000038	0.0000079	0.0000030
5°	0.00074	0.00012	0.000039	0.0000088	0.0000035
15°	0.00092	0.00013	0.000041	0.000010	0.0000042
30°	0.0011	0.00016	0.000048	0.000011	0.0000049
60°	0.0013	0.00025	0.000080	0.000019	0.0000085
90°	0.0014	0.00030	0.000089	0.000021	0.0000095
Surface Temperature = -10° C					
1°	0.0017	0.00026	0.000054	0.000010	0.0000042
5°	0.0017	0.00030	0.000060	0.000011	0.0000046
15°	0.0018	0.00036	0.000099	0.000017	0.0000064
30°	0.0019	0.00041	0.00014	0.000032	0.000014
60°	0.0020	0.00046	0.00016	0.000040	0.000018
90°	0.0020	0.00048	0.00017	0.000042	0.000019

Table XVII

Source Temperature: 400° K

Detector: PbS, 195° K

Values of $E' = 10^4 E$, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.000019	0.0000035	9.9×10^{-7}	----------	----------
5°	0.000019	0.0000035	1.1×10^{-6}	2.0×10^{-7}	----------
15°	0.000019	0.0000040	1.2×10^{-6}	2.7×10^{-7}	1.2×10^{-7}
30°	0.000020	0.0000042	1.4×10^{-6}	3.4×10^{-7}	1.5×10^{-7}
60°	0.000020	0.0000048	1.7×10^{-6}	4.2×10^{-7}	1.9×10^{-7}
90°	0.000021	0.0000050	1.7×10^{-6}	4.3×10^{-7}	1.9×10^{-7}
Surface Temperature = 20° C					
1°	0.000023	0.0000045	1.5×10^{-6}	2.9×10^{-7}	1.1×10^{-7}
5°	0.000024	0.0000046	1.6×10^{-6}	3.3×10^{-7}	1.3×10^{-7}
15°	0.000025	0.0000053	1.7×10^{-6}	4.0×10^{-7}	1.7×10^{-7}
30°	0.000026	0.0000058	1.9×10^{-6}	4.7×10^{-7}	2.0×10^{-7}
60°	0.000028	0.0000063	2.2×10^{-6}	5.6×10^{-7}	2.5×10^{-7}
90°	0.000030	0.0000067	2.3×10^{-6}	5.7×10^{-7}	2.6×10^{-7}
Surface Temperature = 5° C					
1°	0.000056	0.0000069	2.0×10^{-6}	4.1×10^{-7}	1.6×10^{-7}
5°	0.000062	0.0000069	2.1×10^{-6}	4.6×10^{-7}	1.9×10^{-7}
15°	0.000078	0.0000078	2.3×10^{-6}	5.2×10^{-7}	2.3×10^{-7}
30°	0.000095	0.000012	3.2×10^{-6}	6.7×10^{-7}	2.9×10^{-7}
60°	0.00012	0.000022	7.3×10^{-6}	1.7×10^{-6}	7.4×10^{-7}
90°	0.00013	0.000026	7.6×10^{-6}	2.1×10^{-6}	9.2×10^{-7}
Surface Temperature = -10° C					
1°	0.00015	0.000022	4.5×10^{-6}	5.6×10^{-7}	2.2×10^{-7}
5°	0.00016	0.000027	5.1×10^{-6}	6.2×10^{-7}	2.5×10^{-7}
15°	0.00017	0.000032	8.7×10^{-6}	1.4×10^{-6}	4.9×10^{-7}
30°	0.00017	0.000037	1.2×10^{-5}	2.9×10^{-6}	1.3×10^{-6}
60°	0.00018	0.000042	1.5×10^{-5}	3.7×10^{-6}	1.6×10^{-6}
90°	0.00018	0.000043	1.5×10^{-5}	3.7×10^{-6}	1.7×10^{-6}

Table XVIII

Source Temperature: 350° K

Detector: PbS, 195° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.0000026	4.9×10^{-7}	1.2×10^{-7}	----------	----------
5°	0.0000026	4.9×10^{-7}	1.3×10^{-7}	2.0×10^{-8}	----------
15°	0.0000027	5.4×10^{-7}	1.6×10^{-7}	3.3×10^{-8}	1.4×10^{-8}
30°	0.0000029	6.0×10^{-7}	2.0×10^{-7}	4.7×10^{-8}	2.1×10^{-8}
60°	0.0000030	6.8×10^{-7}	2.4×10^{-7}	5.9×10^{-8}	2.6×10^{-8}
90°	0.0000030	7.1×10^{-7}	2.5×10^{-7}	6.2×10^{-8}	2.7×10^{-8}
Surface Temperature = 20° C					
1°	0.0000035	7.1×10^{-7}	2.1×10^{-7}	3.6×10^{-8}	1.2×10^{-8}
5°	0.0000035	7.1×10^{-7}	2.2×10^{-7}	4.4×10^{-8}	1.7×10^{-8}
15°	0.0000037	7.6×10^{-7}	2.5×10^{-7}	5.8×10^{-8}	2.4×10^{-8}
30°	0.0000037	8.2×10^{-7}	2.9×10^{-7}	6.8×10^{-8}	3.0×10^{-8}
60°	0.0000044	9.3×10^{-7}	3.3×10^{-7}	8.0×10^{-8}	3.5×10^{-8}
90°	0.0000046	1.0×10^{-6}	3.5×10^{-7}	8.8×10^{-8}	3.9×10^{-8}
Surface Temperature = 5° C					
1°	0.000010	1.0×10^{-6}	2.9×10^{-7}	5.9×10^{-8}	2.3×10^{-8}
5°	0.000011	1.0×10^{-6}	3.1×10^{-7}	6.5×10^{-8}	2.7×10^{-8}
15°	0.000014	1.2×10^{-6}	3.5×10^{-7}	8.0×10^{-8}	3.3×10^{-8}
30°	0.000017	2.1×10^{-6}	4.8×10^{-7}	1.0×10^{-7}	4.6×10^{-8}
60°	0.000020	3.8×10^{-6}	1.2×10^{-6}	2.9×10^{-7}	1.3×10^{-7}
90°	0.000020	4.3×10^{-6}	1.5×10^{-6}	3.6×10^{-7}	1.6×10^{-7}
Surface Temperature = -10° C					
1°	0.000023	3.9×10^{-6}	7.0×10^{-7}	8.4×10^{-8}	3.2×10^{-8}
5°	0.000023	4.3×10^{-6}	8.9×10^{-7}	9.5×10^{-8}	5.[illegible] $\times 10^{-8}$
15°	0.000025	5.0×10^{-6}	1.4×10^{-6}	2.5×10^{-7}	9.2×10^{-8}
30°	0.000026	5.7×10^{-6}	1.9×10^{-6}	4.5×10^{-7}	2.0×10^{-7}
60°	0.000026	6.2×10^{-6}	2.2×10^{-6}	5.5×10^{-7}	2.4×10^{-7}
90°	0.000027	6.4×10^{-6}	2.3×10^{-6}	5.6×10^{-7}	2.5×10^{-7}

Table XIX

Source Temperature: 1000° K

Detector: PbS, 90° K

Values of $E' = 10^4 E$, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.35	0.075	0.023	------	------
5°	0.35	0.075	0.024	0.0049	------
15°	0.35	0.080	0.026	0.0060	0.0026
30°	0.36	0.085	0.029	0.0072	0.0032
60°	0.36	0.089	0.031	0.0079	0.0035
90°	0.36	0.089	0.032	0.0080	0.0035
Surface Temperature = 20° C					
1°	0.39	0.089	0.030	0.0062	0.0025
5°	0.39	0.089	0.031	0.0068	0.0028
15°	0.41	0.090	0.032	0.0077	0.0034
30°	0.42	0.097	0.033	0.0082	0.0037
60°	0.44	0.10	0.036	0.0090	0.0040
90°	0.46	0.11	0.038	0.0094	0.0041
Surface Temperature = 5° C					
1°	0.53	0.11	0.033	0.0078	0.0032
5°	0.57	0.11	0.035	0.0080	0.0035
15°	0.60	0.12	0.038	0.0088	0.0039
30°	0.64	0.13	0.043	0.010	0.0046
60°	0.67	0.15	0.053	0.013	0.0056
90°	0.69	0.16	0.056	0.014	0.0062
Surface Temperature = -10° C					
1°	0.74	0.15	0.046	0.0091	0.0037
5°	0.74	0.16	0.048	0.0095	0.0041
15°	0.76	0.17	0.056	0.012	0.0053
30°	0.78	0.18	0.064	0.016	0.0067
60°	0.81	0.19	0.070	0.017	0.0078
90°	0.81	0.20	0.070	0.017	0.0078

Table XX

Source Temperature: 800° K

Detector: PbS, 90° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

	Range in Meters				
	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.090	0.021	0.0067	-------	-------
5°	0.092	0.021	0.0068	0.0014	-------
15°	0.092	0.022	0.0073	0.0017	0.00076
30°	0.092	0.022	0.0080	0.0019	0.00085
60°	0.095	0.023	0.0083	0.0021	0.00092
90°	0.098	0.023	0.0083	0.0021	0.00092
Surface Temperature = 20° C					
1°	0.11	0.023	0.0073	0.0017	0.00072
5°	0.11	0.023	0.0081	0.0019	0.00081
15°	0.11	0.024	0.0083	0.0020	0.00088
30°	0.11	0.026	0.0089	0.0022	0.00097
60°	0.12	0.027	0.0097	0.0024	0.0011
90°	0.12	0.028	0.010	0.0025	0.0011
Surface Temperature = 5° C					
1°	0.14	0.028	0.0091	0.0021	0.00088
5°	0.15	0.029	0.0092	0.0021	0.00092
15°	0.16	0.030	0.010	0.0024	0.0010
30°	0.17	0.035	0.011	0.0029	0.0013
60°	0.18	0.040	0.014	0.0035	0.0015
90°	0.18	0.043	0.015	0.0037	0.0016
Surface Temperature = -10° C					
1°	0.20	0.041	0.012	0.0024	0.00097
5°	0.20	0.043	0.013	0.0026	0.0011
15°	0.20	0.046	0.015	0.0033	0.0014
30°	0.21	0.049	0.017	0.0041	0.0018
60°	0.21	0.052	0.018	0.0046	0.0020
90°	0.22	0.053	0.019	0.0047	0.0021

Table XXI

Source Temperature: 600° K

Detector: PbS, 90° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.0065	0.0015	0.00043	--------	--------
5°	0.0067	0.0015	0.00048	0.000088	--------
15°	0.0067	0.0015	0.00051	0.00012	0.000051
30°	0.0069	0.0016	0.00056	0.00013	0.000060
60°	0.0072	0.0017	0.00060	0.00015	0.000067
90°	0.0074	0.0017	0.00060	0.00015	0.000067
Surface Temperature = 20° C					
1°	0.0085	0.0018	0.00057	0.00012	0.000049
5°	0.0088	0.0018	0.00059	0.00013	0.000055
15°	0.0092	0.0019	0.00060	0.00015	0.000064
30°	0.0095	0.0020	0.00070	0.00017	0.000074
60°	0.011	0.0024	0.00083	0.00021	0.000092
90°	0.011	0.0025	0.00086	0.00022	0.000095
Surface Temperature = 5° C					
1°	0.014	0.0025	0.00072	0.00015	0.000064
5°	0.014	0.0025	0.00075	0.00016	0.000067
15°	0.016	0.0028	0.00086	0.00019	0.000083
30°	0.017	0.0034	0.0010	0.00025	0.00011
60°	0.019	0.0041	0.0014	0.00034	0.00015
90°	0.019	0.0043	0.0015	0.00037	0.00017
Surface Temperature = -10° C					
1°	0.021	0.0041	0.0011	0.00020	0.000078
5°	0.021	0.0042	0.0013	0.00023	0.000092
15°	0.022	0.0048	0.0015	0.00033	0.00014
30°	0.023	0.0051	0.0018	0.00042	0.00019
60°	0.023	0.0055	0.0020	0.00048	0.00021
90°	0.023	0.0057	0.0020	0.00049	0.00022

Table XXII

Source Temperature: 500° K

Detector: PbS, 90° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.0017	0.00034	0.000092	---------	---------
5°	0.0017	0.00034	0.00010	0.000019	---------
15°	0.0017	0.00037	0.00012	0.000025	0.000011
30°	0.0018	0.00040	0.00014	0.000033	0.000014
60°	0.0019	0.00044	0.00015	0.000039	0.000017
90°	0.0019	0.00046	0.00016	0.000041	0.000018
Surface Temperature = 20° C					
1°	0.0021	0.00046	0.00014	0.000027	0.000010
5°	0.0021	0.00046	0.00015	0.000031	0.000012
15°	0.0022	0.00049	0.00016	0.000037	0.000017
30°	0.0023	0.00050	0.00017	0.000043	0.000019
60°	0.0025	0.00056	0.00019	0.000049	0.000022
90°	0.0025	0.00057	0.00020	0.000051	0.000023
Surface Temperature = 5° C					
1°	0.0034	0.00058	0.00018	0.000038	0.000015
5°	0.0035	0.00058	0.00018	0.000042	0.000017
15°	0.0037	0.00065	0.00020	0.000047	0.000020
30°	0.0039	0.00080	0.00025	0.000057	0.000026
60°	0.0042	0.00098	0.00033	0.000080	0.000035
90°	0.0042	0.0010	0.00035	0.000088	0.000039
Surface Temperature = -10° C					
1°	0.0046	0.00098	0.00028	0.000049	0.000019
5°	0.0046	0.0010	0.00030	0.000053	0.000022
15°	0.0046	0.0011	0.00035	0.000077	0.000033
30°	0.0047	0.0011	0.00037	0.000088	0.000039
60°	0.0048	0.0012	0.00038	0.000095	0.000042
90°	0.0048	0.0012	0.00042	0.00010	0.000047

Table XXIII

Source Temperature: 400° K

Detector: PbS, 90° K

Values of $E' = 10^4 E$, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.00021	0.000045	0.000013	---------	---------
5°	0.00021	0.000045	0.000014	0.0000031	---------
15°	0.00021	0.000049	0.000016	0.0000040	0.0000016
30°	0.00022	0.000051	0.000017	0.0000048	0.0000019
60°	0.00023	0.000054	0.000019	0.0000054	0.0000021
90°	0.00023	0.000055	0.000020	0.0000055	0.0000022
Surface Temperature = 20° C					
1°	0.00025	0.000056	0.000018	0.0000030	0.0000010
5°	0.00026	0.000056	0.000019	0.0000046	0.0000017
15°	0.00027	0.000058	0.000020	0.0000053	0.0000020
30°	0.00028	0.000062	0.000021	0.0000058	0.0000023
60°	0.00030	0.000069	0.000024	0.0000069	0.0000027
90°	0.00032	0.000071	0.000025	0.0000070	0.0000028
Surface Temperature = 5° C					
1°	0.00039	0.000071	0.000022	0.0000054	0.0000020
5°	0.00041	0.000072	0.000022	0.0000057	0.0000021
15°	0.00044	0.000080	0.000025	0.0000065	0.0000025
30°	0.00046	0.000097	0.000030	0.0000079	0.0000031
60°	0.00049	0.00011	0.000040	0.000011	0.0000042
90°	0.00050	0.00012	0.000041	0.000012	0.0000046
Surface Temperature = -10° C					
1°	0.00051	0.000097	0.000033	0.0000068	0.0000024
5°	0.00051	0.00012	0.000035	0.0000073	0.0000027
15°	0.00052	0.00013	0.000041	0.000010	0.0000039
30°	0.00052	0.00013	0.000045	0.000012	0.0000050
60°	0.00052	0.00013	0.000046	0.000013	0.0000051
90°	0.00052	0.00013	0.000047	0.000013	0.0000051

Table XXIV

Source Temperature: 350° K

Detector: PbS, 90° C

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.000051	0.000011	0.0000029	---------	---------
5°	0.000051	0.000011	0.0000035	5.6×10^{-7}	---------
15°	0.000053	0.000012	0.0000036	8.8×10^{-7}	3.2×10^{-7}
30°	0.000053	0.000012	0.0000043	1.0×10^{-6}	4.6×10^{-7}
60°	0.000055	0.000013	0.0000048	1.2×10^{-6}	5.3×10^{-7}
90°	0.000056	0.000013	0.0000048	1.2×10^{-6}	5.3×10^{-7}
Surface Temperature = 20° C					
1°	0.000060	0.000013	0.0000045	8.8×10^{-7}	3.1×10^{-7}
5°	0.000060	0.000013	0.0000045	1.0×10^{-6}	3.9×10^{-7}
15°	0.000061	0.000014	0.0000048	1.2×10^{-6}	4.9×10^{-7}
30°	0.000064	0.000014	0.0000051	1.3×10^{-6}	5.7×10^{-7}
60°	0.000067	0.000016	0.0000056	1.4×10^{-6}	6.2×10^{-7}
90°	0.000070	0.000016	0.0000057	1.4×10^{-6}	6.4×10^{-7}
Surface Temperature = 5° C					
1°	0.000081	0.000016	0.0000051	1.2×10^{-6}	4.4×10^{-7}
5°	0.000085	0.000016	0.0000052	1.2×10^{-6}	5.3×10^{-7}
15°	0.000088	0.000018	0.0000057	1.4×10^{-6}	5.8×10^{-7}
30°	0.000092	0.000020	0.0000064	1.6×10^{-6}	7.0×10^{-7}
60°	0.000095	0.000022	0.0000079	2.0×10^{-6}	8.8×10^{-7}
90°	0.000095	0.000023	0.0000083	2.1×10^{-6}	9.2×10^{-7}
Surface Temperature = -10° C					
1°	0.00010	0.000023	0.0000070	1.4×10^{-6}	5.6×10^{-7}
5°	0.00010	0.000023	0.0000073	1.5×10^{-6}	6.2×10^{-7}
15°	0.00010	0.000024	0.0000083	1.9×10^{-6}	8.1×10^{-7}
30°	0.00010	0.000024	0.0000088	2.2×10^{-6}	9.5×10^{-7}
60°	0.00011	0.000026	0.0000092	2.3×10^{-6}	1.0×10^{-6}
90°	0.00011	0.000027	0.0000094	2.4×10^{-6}	1.0×10^{-6}

Table XXV

Source Temperature: 1000° K

Detector: PbSe, 195° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

	Range in Meters				
	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.44	0.093	0.027	------	------
5°	0.44	0.093	0.029	0.0060	------
15°	0.46	0.097	0.032	0.0074	0.0032
30°	0.46	0.11	0.037	0.0088	0.0039
60°	0.48	0.12	0.041	0.010	0.0044
90°	0.49	0.12	0.041	0.010	0.0046
Surface Temperature = 20° C					
1°	0.51	0.12	0.037	0.0076	0.0031
5°	0.51	0.12	0.038	0.0084	0.0035
15°	0.52	0.12	0.041	0.010	0.0042
30°	0.53	0.12	0.044	0.011	0.0048
60°	0.55	0.13	0.047	0.012	0.0052
90°	0.56	0.13	0.048	0.012	0.0053
Surface Temperature = 5° C					
1°	0.65	0.13	0.044	0.010	0.0041
5°	0.67	0.13	0.044	0.011	0.0046
15°	0.70	0.14	0.048	0.012	0.0049
30°	0.71	0.16	0.053	0.013	0.0056
60°	0.78	0.18	0.062	0.015	0.0069
90°	0.78	0.19	0.065	0.016	0.0073
Surface Temperature = -10° C					
1°	0.83	0.18	0.056	0.012	0.0049
5°	0.85	0.19	0.059	0.012	0.0051
15°	0.86	0.20	0.065	0.015	0.0063
30°	0.88	0.21	0.073	0.017	0.0078
60°	0.88	0.22	0.076	0.019	0.0085
90°	0.90	0.22	0.080	0.020	0.0088

Table XXVI

Source Temperature: 800° K

Detector: PbSe, 195° C

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.14	0.029	0.0086	-------	-------
5°	0.14	0.029	0.0092	0.0018	-------
15°	0.14	0.032	0.010	0.0023	0.0010
30°	0.14	0.034	0.011	0.0028	0.0012
60°	0.15	0.035	0.013	0.0032	0.0014
90°	0.15	0.035	0.013	0.0032	0.0014
Surface Temperature = 20° C					
1°	0.16	0.036	0.012	0.0024	0.00095
5°	0.16	0.036	0.012	0.0026	0.0011
15°	0.16	0.036	0.013	0.0031	0.0013
30°	0.16	0.037	0.013	0.0033	0.0015
60°	0.17	0.040	0.014	0.0035	0.0016
90°	0.18	0.041	0.014	0.0036	0.0016
Surface Temperature = 5° C					
1°	0.20	0.041	0.013	0.0032	0.0013
5°	0.21	0.042	0.014	0.0033	0.0014
15°	0.22	0.044	0.016	0.0034	0.0015
30°	0.23	0.050	0.017	0.0040	0.0017
60°	0.24	0.056	0.020	0.0048	0.0022
90°	0.24	0.057	0.020	0.0050	0.0022
Surface Temperature = -10° C					
1°	0.25	0.056	0.018	0.0035	0.0015
5°	0.25	0.057	0.018	0.0037	0.0016
15°	0.26	0.060	0.020	0.0047	0.0020
30°	0.26	0.063	0.022	0.0054	0.0024
60°	0.27	0.064	0.024	0.0059	0.0026
90°	0.27	0.066	0.024	0.0059	0.0026

Table XXVII

Source Temperature: 600° K

Detector: PbSe, 195° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.021	0.0045	0.0014	-------	-------
5°	0.022	0.0046	0.0015	0.00029	-------
15°	0.022	0.0049	0.0016	0.00037	0.00016
30°	0.023	0.0052	0.0018	0.00043	0.00019
60°	0.023	0.0057	0.0020	0.00049	0.00022
90°	0.024	0.0058	0.0020	0.00051	0.00023
Surface Temperature = 20° C					
1°	0.025	0.0058	0.0019	0.00038	0.00015
5°	0.025	0.0059	0.0019	0.00041	0.00017
15°	0.025	0.0060	0.0021	0.00048	0.00021
30°	0.026	0.0062	0.0022	0.00053	0.00024
60°	0.027	0.0065	0.0023	0.00057	0.00025
90°	0.028	0.0066	0.0024	0.00059	0.00026
Surface Temperature = 5° C					
1°	0.031	0.0065	0.0022	0.00049	0.00020
5°	0.032	0.0066	0.0022	0.00052	0.00023
15°	0.033	0.0071	0.0024	0.00056	0.00025
30°	0.034	0.0076	0.0026	0.00063	0.00028
60°	0.035	0.0083	0.0030	0.00073	0.00032
90°	0.035	0.0086	0.0031	0.00076	0.00034
Surface Temperature = -10° C					
1°	0.038	0.0084	0.0027	0.00057	0.00024
5°	0.038	0.0087	0.0028	0.00060	0.00025
15°	0.039	0.0089	0.0030	0.00072	0.00031
30°	0.039	0.0095	0.0033	0.00080	0.00035
60°	0.040	0.0098	0.0035	0.00088	0.00039
90°	0.040	0.010	0.0035	0.00088	0.00039

Table XXVIII

Source Temperature: 500° K

Detector: PbSe, 195° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.0062	0.0013	0.00038	--------	--------
5°	0.0062	0.0013	0.00040	0.000075	--------
15°	0.0064	0.0014	0.00044	0.00011	0.000048
30°	0.0067	0.0015	0.00051	0.00012	0.000053
60°	0.0067	0.0016	0.00057	0.00014	0.000063
90°	0.0067	0.0017	0.00060	0.00015	0.000067
Surface Temperature = 20° C					
1°	0.0071	0.0017	0.00051	0.00010	0.000042
5°	0.0071	0.0017	0.00054	0.00012	0.000048
15°	0.0071	0.0017	0.00060	0.00013	0.000060
30°	0.0072	0.0017	0.00060	0.00015	0.000067
60°	0.0074	0.0018	0.00064	0.00016	0.000071
90°	0.0074	0.0018	0.00065	0.00016	0.000072
Surface Temperature = 5° C					
1°	0.0085	0.0018	0.00062	0.00014	0.000056
5°	0.0087	0.0019	0.00064	0.00015	0.000064
15°	0.0088	0.0019	0.00065	0.00016	0.000069
30°	0.0092	0.0021	0.00070	0.00017	0.000074
60°	0.0095	0.0023	0.00079	0.00020	0.000088
90°	0.0095	0.0023	0.00083	0.00021	0.000092
Surface Temperature = -10° C					
1°	0.0099	0.0023	0.00073	0.00016	0.000069
5°	0.0099	0.0023	0.00076	0.00017	0.000071
15°	0.010	0.0024	0.00083	0.00019	0.000085
30°	0.010	0.0025	0.00087	0.00021	0.000095
60°	0.010	0.0026	0.00091	0.00023	0.00010
90°	0.010	0.0026	0.00092	0.00023	0.00010

Table XXIX

Source Temperature: 400° K

Detector: PbSe, 195° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.00095	0.00020	0.000057	--------	---------
5°	0.00095	0.00020	0.000057	0.000015	---------
15°	0.00095	0.00022	0.000070	0.000016	0.0000067
30°	0.00095	0.00023	0.000079	0.000019	0.0000085
60°	0.00095	0.00024	0.000086	0.000021	0.0000095
90°	0.00097	0.00024	0.000086	0.000021	0.0000095
Surface Temperature = 20° C					
1°	0.00099	0.00024	0.000083	0.000017	0.0000063
5°	0.0010	0.00024	0.000086	0.000018	0.0000074
15°	0.0010	0.00024	0.000086	0.000022	0.0000094
30°	0.0010	0.00025	0.000088	0.000022	0.0000097
60°	0.0011	0.00026	0.000092	0.000023	0.000010
90°	0.0011	0.00026	0.000092	0.000023	0.000010
Surface Temperature = 5° C					
1°	0.0011	0.00026	0.000089	0.000022	0.0000090
5°	0.0011	0.00026	0.000089	0.000022	0.0000095
15°	0.0012	0.00027	0.000092	0.000023	0.0000099
30°	0.0012	0.00028	0.000099	0.000024	0.000011
60°	0.0013	0.00030	0.00010	0.000026	0.000012
90°	0.0013	0.00031	0.00011	0.000027	0.000012
Surface Temperature = -10° C					
1°	0.0014	0.00030	0.00010	0.000023	0.0000097
5°	0.0014	0.00031	0.00010	0.000024	0.000010
15°	0.0014	0.00033	0.00011	0.000026	0.000011
30°	0.0014	0.00035	0.00012	0.000029	0.000013
60°	0.0014	0.00035	0.00012	0.000031	0.000014
90°	0.0014	0.00035	0.00012	0.000031	0.000014

Table XXX

Source Temperature: 350° K

Detector: PbSe, 195° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

	Range in Meters				
	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.00022	0.000047	0.000014	---------	---------
5°	0.00022	0.000047	0.000015	0.0000032	---------
15°	0.00023	0.000050	0.000016	0.0000037	0.0000016
30°	0.00023	0.000053	0.000018	0.0000044	0.0000019
60°	0.00024	0.000057	0.000020	0.0000050	0.0000022
90°	0.00024	0.000059	0.000021	0.0000053	0.0000023
Surface Temperature = 20° C					
1°	0.00025	0.000059	0.000019	0.0000039	0.0000016
5°	0.00025	0.000059	0.000019	0.0000046	0.0000018
15°	0.00025	0.000060	0.000021	0.0000050	0.0000021
30°	0.00025	0.000062	0.000022	0.0000054	0.0000024
60°	0.00026	0.000062	0.000022	0.0000056	0.0000025
90°	0.00026	0.000063	0.000022	0.0000056	0.0000025
Surface Temperature = 5° C					
1°	0.00028	0.000062	0.000022	0.0000050	0.0000020
5°	0.00028	0.000064	0.000022	0.0000053	0.0000023
15°	0.00028	0.000065	0.000023	0.0000056	0.0000025
30°	0.00029	0.000069	0.000024	0.0000059	0.0000026
60°	0.00029	0.000072	0.000025	0.0000064	0.0000028
90°	0.00029	0.000072	0.000026	0.0000064	0.0000029
Surface Temperature = -10° C					
1°	0.000030	0.000072	0.000025	0.0000056	0.0000024
5°	0.000030	0.000072	0.000025	0.0000057	0.0000025
15°	0.000030	0.000072	0.000026	0.0000063	0.0000028
30°	0.000030	0.000074	0.000027	0.0000063	0.0000029
60°	0.000030	0.000074	0.000027	0.0000067	0.0000030
90°	0.000030	0.000075	0.000027	0.0000067	0.0000030

Table XXXI

Source Temperature: 1000° K

Detector: PbSe, 90° K

Values of $E' = 10^4 E$, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.58	0.11	0.032	------	------
5°	0.58	0.12	0.035	0.0072	------
15°	0.60	0.13	0.040	0.0088	0.0039
30°	0.63	0.14	0.046	0.011	0.0049
60°	0.65	0.15	0.054	0.013	0.0060
90°	0.67	0.16	0.056	0.014	0.0065
Surface Temperature = 20° C					
1°	0.71	0.16	0.048	------	0.0035
5°	0.71	0.16	0.051	0.010	0.0042
15°	0.71	0.17	0.056	0.013	0.0056
30°	0.71	0.18	0.060	0.015	0.0067
60°	0.74	0.18	0.064	0.016	0.0071
90°	0.74	0.18	0.064	0.016	0.0071
Surface Temperature = 5° C					
1°	0.85	0.18	0.062	0.014	0.0053
5°	0.87	0.18	0.064	0.014	0.0060
15°	0.90	0.19	0.064	0.016	0.0071
30°	0.93	0.20	0.068	0.017	0.0074
60°	0.99	0.23	0.082	0.020	0.0088
90°	1.0	0.24	0.088	0.022	0.0097
Surface Temperature = -10° C					
1°	1.1	0.23	0.073	0.016	0.0069
5°	1.1	0.24	0.077	0.016	0.0071
15°	1.1	0.25	0.085	0.020	0.0081
30°	1.1	0.27	0.092	0.023	0.010
60°	1.1	0.28	0.099	0.025	0.011
90°	1.2	0.28	0.10	0.026	0.011

Table XXXII

Source Temperature: 800° K

Detector: PbSe, 90° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.18	0.036	0.010	------	------
5°	0.18	0.036	0.011	0.0021	------
15°	0.19	0.039	0.013	0.0029	0.0012
30°	0.19	0.042	0.014	0.0034	0.0015
60°	0.19	0.047	0.016	0.0041	0.0018
90°	0.19	0.048	0.017	0.0042	0.0019
Surface Temperature = 20° C					
1°	0.20	0.048	0.015	0.0030	0.0012
5°	0.20	0.048	0.016	0.0033	0.0013
15°	0.21	0.049	0.017	0.0040	0.0017
30°	0.22	0.049	0.018	0.0044	0.0019
60°	0.23	0.053	0.019	0.0047	0.0021
90°	0.24	0.055	0.019	0.0048	0.0021
Surface Temperature = 5° C					
1°	0.28	0.055	0.018	0.0041	0.0016
5°	0.28	0.056	0.018	0.0043	0.0019
15°	0.29	0.061	0.020	0.0046	0.0020
30°	0.30	0.067	0.023	0.0054	0.0024
60°	0.32	0.076	0.026	0.0065	0.0029
90°	0.32	0.077	0.027	0.0068	0.0030
Surface Temperature = -10° C					
1°	0.34	0.075	0.024	0.0047	0.0019
5°	0.34	0.077	0.025	0.0051	0.0021
15°	0.35	0.081	0.027	0.0064	0.0028
30°	0.35	0.084	0.029	0.0072	0.0032
60°	0.35	0.087	0.031	0.0078	0.0035
90°	0.35	0.089	0.032	0.0079	0.0035

Table XXXIII

Source Temperature: 600° K

Detector: PbSe, 90° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.037	0.0075	0.0020	-------	-------
5°	0.037	0.0076	0.0022	0.00042	-------
15°	0.039	0.0082	0.0026	0.00057	0.00025
30°	0.041	0.0089	0.0030	0.00071	0.00032
60°	0.041	0.0098	0.0035	0.00088	0.00039
90°	0.042	0.010	0.0035	0.00088	0.00039
Surface Temperature = 20° C					
1°	0.044	0.010	0.0032	0.00060	0.00022
5°	0.044	0.010	0.0033	0.00068	0.00028
15°	0.046	0.011	0.0035	0.00083	0.00035
30°	0.046	0.011	0.0038	0.00095	0.00042
60°	0.049	0.012	0.0041	0.0010	0.00046
90°	0.049	0.012	0.0041	0.0010	0.00046
Surface Temperature = 5° C					
1°	0.055	0.012	0.0038	0.00088	0.00035
5°	0.055	0.012	0.0040	0.00091	0.00035
15°	0.057	0.012	0.0041	0.0010	0.00044
30°	0.058	0.013	0.0046	0.0011	0.00049
60°	0.060	0.014	0.0051	0.0013	0.00056
90°	0.062	0.015	0.0053	0.0013	0.00058
Surface Temperature = -10° C					
1°	0.064	0.014	0.0048	0.0010	0.00042
5°	0.064	0.015	0.0050	0.0010	0.00046
15°	0.065	0.015	0.0053	0.0012	0.00053
30°	0.067	0.016	0.0056	0.0014	0.00062
60°	0.067	0.017	0.0059	0.0015	0.00065
90°	0.067	0.017	0.0060	0.0015	0.00067

Table XXXIV

Source Temperature: 500° K

Detector: PbSe, 90° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.011	0.0022	0.00060	--------	--------
5°	0.011	0.0022	0.00067	0.00012	--------
15°	0.011	0.0024	0.00076	0.00017	0.000071
30°	0.012	0.0027	0.00089	0.00021	0.000095
60°	0.012	0.0028	0.0010	0.00025	0.00011
90°	0.012	0.0029	0.0010	0.00026	0.00012
Surface Temperature = 20° C					
1°	0.013	0.0029	0.00092	0.00017	0.000067
5°	0.013	0.0029	0.00095	0.00020	0.000081
15°	0.013	0.0030	0.0010	0.00025	0.00011
30°	0.014	0.0032	0.0011	0.00027	0.00012
60°	0.014	0.0034	0.0012	0.00029	0.00013
90°	0.014	0.0035	0.0012	0.00030	0.00013
Surface Temperature = 5° C					
1°	0.016	0.0035	0.0011	0.00025	0.000099
5°	0.016	0.0035	0.0011	0.00026	0.00011
15°	0.016	0.0036	0.0012	0.00029	0.00013
30°	0.017	0.0039	0.0013	0.00032	0.00014
60°	0.017	0.0042	0.0015	0.00036	0.00016
90°	0.018	0.0043	0.0015	0.00038	0.00017
Surface Temperature = -10° C					
1°	0.018	0.0042	0.0014	0.00030	0.00012
5°	0.018	0.0043	0.0014	0.00032	0.00013
15°	0.019	0.0044	0.0015	0.00036	0.00016
30°	0.019	0.0047	0.0016	0.00040	0.00018
60°	0.019	0.0048	0.0017	0.00042	0.00019
90°	0.019	0.0049	0.0017	0.00042	0.00019

Table XXXV

Source Temperature: 400° K

Detector: PbSe, 90° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

Range in Meters

Surface Temperature = 35° C

	3,000	6,000	10,000	20,000	30,000
1°	0.0017	0.00033	0.000075	---------	---------
5°	0.0017	0.00033	0.000084	0.000016	---------
15°	0.0017	0.00036	0.00011	0.000023	0.0000099
30°	0.0018	0.00041	0.00013	0.000031	0.000014
60°	0.0019	0.00046	0.00016	0.000040	0.000017
90°	0.0020	0.00048	0.00017	0.000042	0.000018

Surface Temperature = 20° C

	3,000	6,000	10,000	20,000	30,000
1°	0.0021	0.00048	0.00014	0.000025	0.0000085
5°	0.0022	0.00049	0.00015	0.000030	0.000012
15°	0.0022	0.00051	0.00017	0.000038	0.000016
30°	0.0023	0.00055	0.00019	0.000046	0.000020
60°	0.0024	0.00059	0.00021	0.000052	0.000022
90°	0.0024	0.00060	0.00022	0.000054	0.000023

Surface Temperature = 5° C

	3,000	6,000	10,000	20,000	30,000
1°	0.0025	0.00060	0.00019	0.000040	0.000015
5°	0.0026	0.00061	0.00020	0.000044	0.000017
15°	0.0026	0.00064	0.00022	0.000051	0.000021
30°	0.0027	0.00065	0.00023	0.000056	0.000024
60°	0.0028	0.00069	0.00025	0.000061	0.000026
90°	0.0028	0.00071	0.00025	0.000063	0.000027

Surface Temperature = -10° C

	3,000	6,000	10,000	20,000	30,000
1°	0.0029	0.00069	0.00024	0.000052	0.000020
5°	0.0029	0.00071	0.00024	0.000056	0.000022
15°	0.0029	0.00072	0.00025	0.000060	0.000025
30°	0.0029	0.00074	0.00026	0.000065	0.000028
60°	0.0030	0.00077	0.00027	0.000068	0.000029
90°	0.0030	0.00078	0.00028	0.000070	0.000030

Table XXXVI

Source Temperature: 350° K

Detector: PbSe, 90° K

Values of E' = 10^4 E, where E is in ergs/(sec-cm^4)

	Range in Meters				
	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	0.00039	0.000071	0.000019	---------	---------
5°	0.00039	0.000072	0.000020	0.0000037	---------
15°	0.00042	0.000081	0.000025	0.0000052	0.0000020
30°	0.00046	0.000089	0.000030	0.0000072	0.0000032
60°	0.00048	0.00011	0.000035	0.0000088	0.0000039
90°	0.00049	0.00011	0.000040	0.0000095	0.0000042
Surface Temperature = 20° C					
1°	0.00056	0.00011	0.000031	0.0000059	0.0000020
5°	0.00058	0.00011	0.000033	0.0000065	0.0000025
15°	0.00060	0.00012	0.000040	0.0000088	0.0000037
30°	0.00064	0.00014	0.000046	0.000011	0.0000049
60°	0.00067	0.00015	0.000054	0.000014	0.0000060
90°	0.00067	0.00016	0.000056	0.000014	0.0000062
Surface Temperature = 5° C					
1°	0.00071	0.00016	0.000048	0.0000095	0.0000034
5°	0.00071	0.00016	0.000051	0.000010	0.0000042
15°	0.00071	0.00017	0.000056	0.000013	0.0000056
30°	0.00073	0.00018	0.000060	0.000015	0.0000067
60°	0.00074	0.00018	0.000064	0.000016	0.0000071
90°	0.00074	0.00018	0.000065	0.000016	0.0000073
Surface Temperature = -10° C					
1°	0.00076	0.00018	0.000062	0.000014	0.0000053
5°	0.00076	0.00018	0.000064	0.000014	0.0000060
15°	0.00076	0.00019	0.000065	0.000016	0.0000071
30°	0.00078	0.00019	0.000067	0.000017	0.0000074
60°	0.00078	0.00020	0.000070	0.000017	0.0000078
90°	0.00078	0.00020	0.000070	0.000017	0.0000078

Table A

Equivalent Thickness of Water Vapor in Centimeters

Range in Meters

	3,000	6,000	10,000	20,000	30,000
Surface Temperature = 35° C					
1°	11.5	22.0	38.1	76.4	108.0
5°	11.0	21.5	32.8	55.5	71.8
15°	10.1	17.3	24.1	31.8	34.1
30°	8.85	13.40	16.30	18.10	18.35
60°	7.18	9.46	10.30	10.60	10.60
90°	6.69	8.47	9.05	9.16	9.16
Surface Temperature = 20° C					
1°	4.5	8.3	14.4	28.9	40.8
5°	4.20	8.15	12.35	20.8	27.0
15°	3.80	6.53	9.02	11.90	12.80
30°	3.32	5.02	6.10	6.80	6.89
60°	2.69	3.55	3.86	3.96	3.96
90°	2.51	3.18	3.41	3.44	3.44
Surface Temperature = 5° C					
1°	1.75	3.20	5.52	10.8	15.4
5°	1.63	3.08	4.78	7.80	10.1
15°	1.43	2.45	3.38	4.45	4.80
30°	1.25	1.88	2.28	2.54	2.58
60°	1.01	1.33	1.45	1.51	1.51
90°	0.94	1.19	1.27	1.29	1.29
Surface Temperature = -10° C					
1°	0.656	1.315	1.97	3.94	5.91
5°	0.63	1.18	1.76	2.97	3.81
15°	0.53	0.93	1.27	1.66	1.80
30°	0.47	0.70	0.85	0.94	0.96
60°	0.38	0.50	0.54	0.55	0.55
90°	0.35	0.44	0.47	0.48	0.48

Summary of Available Information on Infrared Target Radiation

R. Clark Jones

February 24, 1949

The papers are identified on the list attached at the end of this report.

Paper 1C

This report is a translation of the summary and bibliography of a German document. The main portion of the original document has not been found. The report is concerned with the total heat radiation from four cycle motors of unspecified power. It is stated that the total heat output for the motors studied is roughly two percent of the rated output of the motors. Correspondingly, the radiation from the exhaust gases (primarily at 2.7 and 4.3 microns) is only about 0.1 percent of the rated power. The temperature of the exhaust gases decreases exponentionally in the direction of the exhaust. The difference between the exhaust temperature and the ambient temperature decreases to 10 percent of the original value at 60 centimeters.

Paper 2C

The measurements reported are on a single Derwent V jet engine. The power radiated backward at maximum speed corresponds to an isotropic radiator with a power of 5 kilowatts. The power drops to 3 kilowatts at an angle of 35° from the backward direction. The power of the engine is unstated, but it is probably about 5000 horsepower. If this guess of the total power is correct, the total power radiated referred to the backward direction is only slightly more than 0.1 percent of the engine power. The power radiated from the gas stream is only 50 watts.

Paper 3C

This report contains measurements of temperature by means of photocells.

Paper 4C

This paper is concerned with the infrared radiation from the boundary layer of a high speed missile. The concern in the paper is exclusively with the effect of this radiation on a heat detector located in the missile.

Paper 6C

"The primary object of this project is to develop techniques for measuring spectral characteristics of various circumstances, particularly in the infrared and to develop radiation standards for radiometric calibration." There is no information on target radiation in this report.

Paper 7C

This is a theoretical study of the heating by skin friction. The equilibrium skin temperature is summarized in Fig. 1 and 2. At sea level the increase of temperature is 200° F at 1000 miles per hour, 700° F at 2000 miles per hour, and 1500° F at 3000 miles per hour. These figures refer to the increase in the equilibrium temperature of the surface of the missile.

Paper 8C

"The object of the work covered by this report was the measurement of spectral and total radiation intensities emitted by jet engines with special reference to the radiation of exhaust gases in the infrared region. The coordination and development of suitable instruments and equipment for carrying out these measurements were a necessary part of the work." A summary of the results is contained on pages 19 through 22. Figure 55 and Figs. 67 to 88 are of particular interest.

Paper 9C

This brief report is the actual measured skin temperature of a flight of the A-4. The skin temperature rises to a peak of 600° C during the descent into the atmosphere.

Paper 10C

This German report is a very important study of the total radiation within the lead sulfide band of a number of different aircraft as a function of horizontal azimuth and also in the downward direction. Measurements were made with the planes in flight and also stationary.

Paper 11C

No information on radiation.

Paper 12C

This report is a supplement to Paper 4C.

Paper 13C

This report describes rather carefully measurements of the sky radiation. Measurements were made with apparatus covering three different spectral intervals approximately 0.4 to 0.8 micron, 1.0 to 3.0 microns, and 5 to 13 microns.

Paper 14C

This is a translation of Paper 10C.

Paper 15C

"One infrared receiver employed a cooled German Elac lead sulfide cell mounted in a 12 inch aperture thirty inch focal length parabolic mirror. The unit was mounted on the Gun Director and boresighted with the 25 power binoculars. The sensitive area of the cell was 6 x 6 mm and the field of view was limited to a square about 25 minutes on each side by an aperture at the exact focus of the mirror. A toothed wheel in front of the aperture chopped the radiation 800 times a second. The size of the chopper teeth and the openings between the teeth were equal and the aperture was equal in size to a tooth and an opening. The cell was located just behind the aperture. As a result the flux from a uniform background passing by the chopper remained constant and unmodulated. This prevented the sky from producing a signal in the absence of a target. The cell was sensitive to radiation of wavelengths from 0.6 to 3 microns with maximum response at 2.5 microns and was cooled with dry ice to increase sensitivity. The output of this aperatus was amplified and applied to an Esterline Angus recorder.

"A strong signal was recorded from the rocket with the lead sulfide receiver from the time the fuel was ignited until it was cut off at a height of 19 miles and slant range of 21 miles. One feature of the record was that the signal remained at almost a constant amplitude. The explanation appeared to be that as the range increased the total mass of atmospheric attenuation decreased and the two effects happened to compensate. The signal was strong during the entire burning period and then suddenly fell to zero. An estimate of the energy received was obtained by placing a small stop over the mirror and pointing the unit at the sun

at noon. When the response was equal to that from the rocket the calculated flux density from 0.6 to 3 microns was 40 ergs cm^{-2} sec^{-1}. No signal at all was received after Brenschluss and it was concluded that the lead sulfide cell responded only to the infrared emission from the hot gases in the exhaust."

Paper 16C

This report describes an eight-line scanning system using thermocouples. The system appears very crude and the results very poor.

Paper 17C

Although this report contains no data on the radiation of aircraft, the information on ship radiation should be very useful.

Paper 18C

This report concerns the theory of the temperature of the boundary layer and the skin temperature of a high speed missile.

rcj/cbb

Reports re Target Radiation

Group C

1C Halstead Exploiting Centre, Infrared Radiation from Gasoline Engines and Their Exhaust Gases, Report No. HEC 5416, August 28, 1945

2C M. Bound, A. Hobson, V. Rogulsky, Measurements of the Infra-red Radiation from a Single Derwent V Jet Engine, A.S.R.E. Monograph No. 818, Admiralty Signal and Radar Establishment, February, 1948

3C M. Treu, Temperature Measurements with Photocells, Report No. 264, University of Prague, July, 1943

4C Victor Neuman and L. P. Raichle, translators, Infra-red Radiation from the Boundary Layer of Missile "Wasserfall" in Motion, Archive No. 66/116, Naval Ordnance Laboratory, July 15, 1943

5C Jng. Schwenkhagen, Registration of Interference Radiation in the Atmosphere, and Range Measuring Apparatus, Report Nos. SS 0082/4430/42 and SS 0082/4431/42, Northwestern University, Contract No. NObs 28373, February 7, 1947

6C R. V. Dunkle, Thermal Radiation Project Quarterly Progress Report No. 1, University of California, Contract No. N7-onr-295 Task I, August 12, 1947

7C J. L. Byrne, Aerodynamic Heating, Report No. GM-102 (AM-40), Northrop Aircraft, Inc., Project 25, January, 1947

8C C. M. Wolfe, Final Report on Contract No. NOa(s)-8472, Aerojet Engineering Corporation, September 30, 1947

9C C. R. Haave, Skin Temperature of the A-4 During Flight, Naval Ordnance Laboratory Memorandum No. 8682 (H.V.A. Archive No. 66/5) August 15, 1946

10C Wolfgang Plumeyer, Investigation of the Infra-red Radiation characteristics of Aircraft, Document Report No. 1, Office of the Theater Chief Signal Officer, September 8, 1945

11C C. M. Wolfe, Progress Report No. 956-12, Aerojet Engineering Corporation, Contract No. NOa(s)-8620

12C Victor Neuman and L. P. Raichle, translators, Infra-red Radiation from the Boundary Layer of Missile "Wasserfall" in Motion, First Supplement to Archive Report No. 66/116 of 7-15-43, Naval Ordnance Laboratory, September 20, 1943

13C C. P. Butler and G. L. Harvey, Sky Radiation Measurements at White Sands, New Mexico, Report No. H-3069, Naval Research Laboratory, February 4, 1947

14C Wolfgang Plumeyer, Will Vandermeer, translator, Investigation of Infra-red Radiation in Aircraft, Gottingen Report No. UM 714, Ryan Aeronautical Company, June 10, 1946

15C C. P. Butler and G. L. Harvey, Infrared Detection of the A-4 (V-2) Rocket, results of - Preliminary Report on - Physical Optics Division, S78-1(119) (610) 600-128/46, Naval Research Laboratory, July 10, 1946

16C Office of the Theater Chief Signal Officer, Infra-red Image Device with Scanning by Means of a Thermo-element Series, Document Report No. 189, December 17, 1945

17C John Strong, Thermal Radiation from Targets and Backgrounds, OSRD Report No. 5372, Harvard University, Contract No. OEMsr-60, March 30, 1945

18C V. Neuman, translator, Calculation and Discussion of Skin Temperatures T_{B1} for the "Wasserfall" Project for Flat and Steep Trajectories, Archive No. 66/168, F2 0-2039-47, Office of Naval Intelligence, Technical Intelligence Center

MEASUREMENTS ON COMPRESSION CIRCUITS

January 7, 1949

Harry Stockman

1. Introduction

An interesting problem has been encountered, in which the output voltage vs. input voltage curve for a pulse amplifier was to be given a particular shape, representing a small, specified amount of compression at low input voltages, and a large, specified amount of compression for high input voltages. The encountered, single pulses were of approximate duration 0.1 seconds, and had a dynamic range of over 100 decibels in voltage (dbv, the input and output impedances had predetermined values). It was tentatively decided that the initial part of the compression curve should represent a 1:2 ratio between the decibel scales, while the major part of the curve should represent a 1:6 ratio. The problem is complicated by the fact that the amplifier must operate equally well on positive as on negative pulses, and ensuing positive and negative voltage transients.

Several solutions have been considered, but the original problem will not be further discussed here. Instead, the general form of two solutions will be inspected, and the predictions made analytically checked experimentally. The following text and figures merely state the results from the experimental investigations. No attempt has been made at this point to rigorously apply the results to the original problem. The measurement results only serve to indicate that if the suggested types of circuits are used, a resulting compression curve of essentially the desired form obtains.

2. Feedback Cathode Follower Circuit

The first experimental investigation concerns the use of an individual, cathode follower feedback loop for each amplifying stage, so that the

pulse amplitude is compressed, first in the output amplifier stage, then in the previous amplifier stage, and finally, at the end of the signal dynamic range, in the input amplifier stage. A simple direct current circuit is investigated, as elaborate pulse transmission test facilities were not available at the time. No attention has been given the technical problem of obtaining electrode biases, etc., or the problem of how to arrange the feedback loop to act on both signs of the incoming pulse (this can be done by means of phase reversal tubes). The measurements on the cathode follower loop have been in the form of estimations rather than plotted, accurate curves, and response curve is submitted with this report. The measurements prove, however, that a smooth change of the feedback transmission constant obtains when the grid bias (actually signal) voltage is varied through the feedback region.

3. Attenuating Diode-pair Circuit.

The second experimental investigation concerns the use of shunting diodes, or pair of opposite polarity diodes, between grid and ground of each amplifying tube, so that, on conduction, the voltage drop in a series resistor causes the desired loss in output voltage, increasing with the amplitude of the applied signal. The measurements have been carried out for direct voltage conditions only. It is attempted to prove that if two consecutive diode loops are used, the desired shape of compression curve can be obtained, but the alternative of using a third, additional diode loop for better result exists, of course. The amplifying tubes between the diode networks, adding consecutively to the desired compression, are operated linearly, as grid current damping

in these tubes would upset the symmetry of the circuit to pulses of opposite sign.

The experimental, basic circuit for diode compression is shown in the upper part of Figure 1. The two diodes are biased by proper sources as indicated. Additional resistors to serve as adjustments may be inserted from each plate to ground.

The second diode is biased approximately 0.5 volts negative, so that plate current will commence to flow already for a value of V_{in} of a few tenths of a volt. The voltage V_{out} will then start to drop at a slow rate, essentially determined by the resistor R_2. The first diode is biased at approximately 3/4 volts and goes into action later, however with a dynamic characteristic more closely following the tube characteristic. The voltage drop due to the first diode is essentially controlled by R_1. (For reasons of simplified calculations, with the loading on R_1 by the second diode D_2 neglected, R_2 was originally given a much larger value than R_1.) The second diode starts to take appreciable current at the point on the final compression curve, where the action of the first diode tends to become linear. In this way the resulting, curved part of the characteristic is extended, while the flat part suddenly takes over to yield a high amount of compression, represented by a straight line in the diagram. To permit the use of relatively large R_1 and R_2 values without experiencing a heavily suppressed upper part of the characteristic, the resistors R_3 and R_4 have been inserted. These resistors are only active to an appreciable extent on the bend and upper part of the final response curve, where the plate current is large, and thus provide very convenient controls for slope regulation here. By adjusting the various controls for resistance and bias values, the resulting curve can be made to closely re-

semble the desired one. At approximately 5 volts input voltage, the final response curve continues as a straight line of excessive slope. This is the point where the nonlinear networks preceding the amplifying tube should take over and add compression so as to secure the desired response.

4. Feedback Diode-Pair Circuit

It is of interest to consider a compression circuit operating simultaneously with feedback and output nonlinear network attenuation. Such a circuit may be obtained by combining the idea of the cathode follower feedback loop with the idea of the attenuating diode-pair. Generally, output attenuation will reduce the output of the stage without affecting the gain of the tube, while feedback will change the gain without affecting the output voltage obtained from the regulated tube. The two compression systems have different characteristics and response curves, and by changing the parameters in the circuit to be described, one can go from one extreme to the other, obtaining any desirable combination of the two actions.

Figure 3 shows several response curves which illustrate how the shape of the response curve can be conveniently changed by proper use of the many parameters in the circuit, Figure 2. While attenuation only provides a certain compression, feedback action will produce a definite limiting action. The percentage figure given is simply calculated as R_4/R_3 and only serves as qualitative information about the amount of feedback used. Due to the fact that a changed position of the tap on the potentiometer R_3 not only changes the amount of feedback, but also to some extent the steady bias voltage on the grid, a small correction should be introduced in the diagram, Figure 3. Nevertheless the trend

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of utilizing negative feedback is obvious.

The curve for R_2 = 37000 ohms has a tendency to bend upwards, and generally, the effect of R_2 increases with the signal amplitude. This fact is of little significance as the total attenuation for the upper part of the dynamic range in Fig. 3 is handled by the compression circuits of previous amplifier stages.

HS/h

Diode Compression Circuit

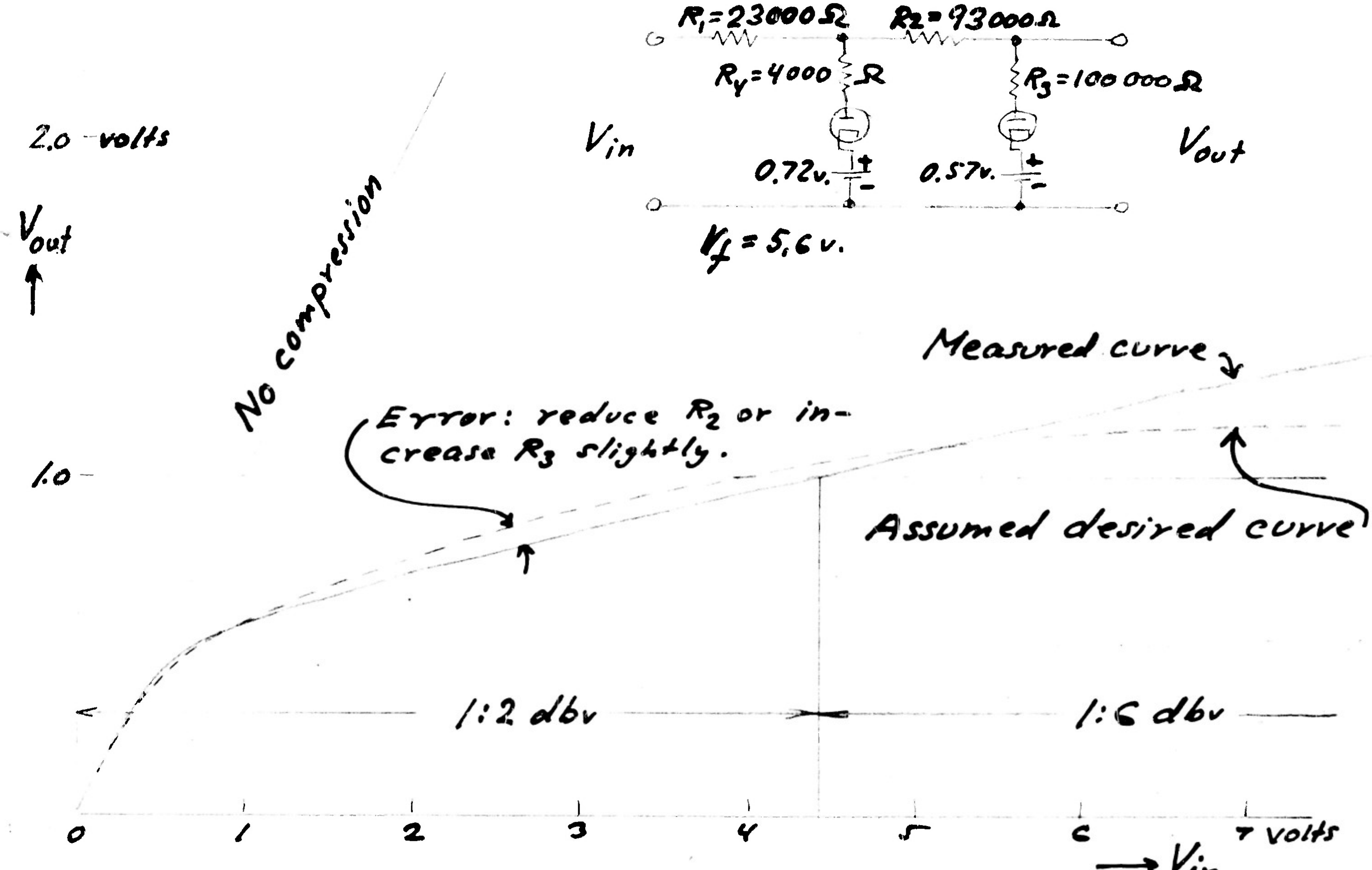

Fig. 1.

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Diode Feedback Circuit

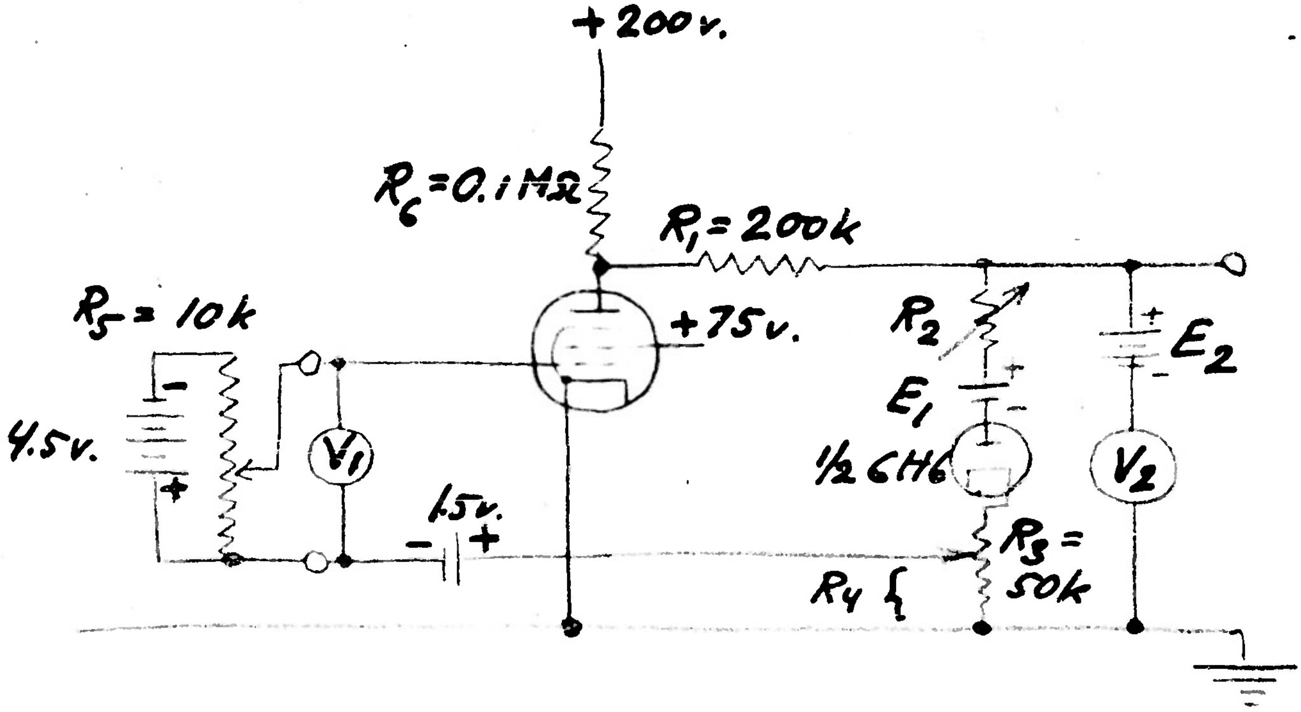

Fig. 2

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Diode Feedback Curves

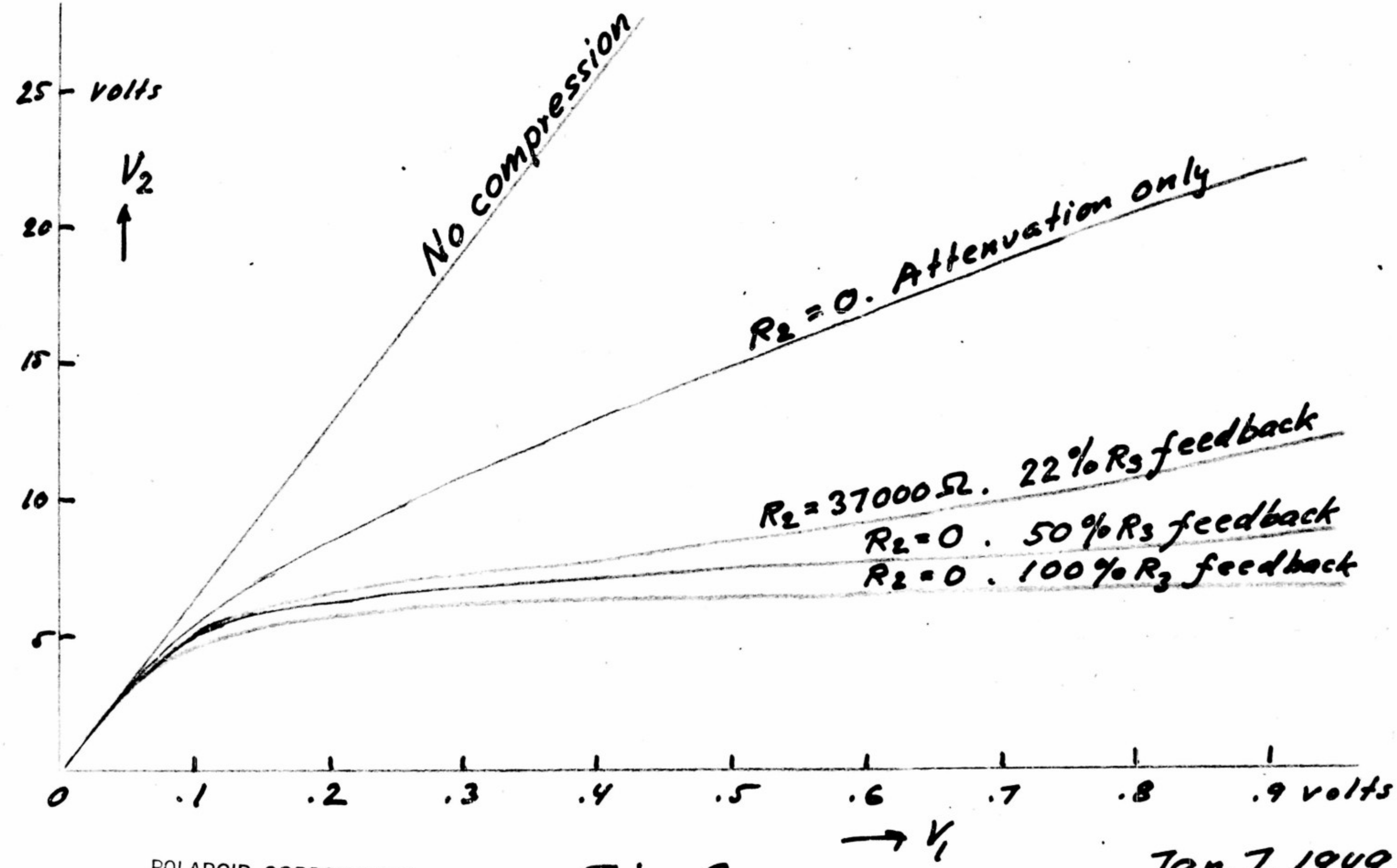

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Fig. 3

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CHANNEL AMPLIFIER DESIGN

January 7, 1949

Harry Stockman

1. Basic Considerations:

The design work on this and the adjacent two amplifiers may be divided into three major parts, concerning

1. Amplitude (or power) response
2. Waveform (or phase) response
3. Signal-to-noise ratio.

The following discussion deals essentially with item 1. This item includes ways and means for Automatic Gain Control, AGC, or signal compression. To not unnecessarily invite difficulties in form of instability problems and signal-to-noise problems, AGC has not been applied to the cell-amplifier. To restrict the signal dynamic range on the switching tube, all AGC action is initially restricted to the channel amplifier. Large signal limiting may, however, be applied to the CRO amplifier so as to prevent "blooming" on the CRO screen.

The AGC problem should be simplified if a "lin-log" type of channel amplifier could be used without any compression at all for the initial signal dynamic range. This would, however, involve a very high amount of compression on the stronger signals, and result in a sharp knee on the voltage output vs. voltage input curve, which is not desirable. Accordingly a curve such as the tentative curve in Fig. 1 should be aimed at, where a smaller amount of fixed ratio compression (1:2) is applied for signals ± 10 dbv around the noise level, while a higher amount of fixed ratio compression (1:6) is used for the remaining part of the dynamic range. The vertical scale is restricted to 25 dbv on the assumption that this variation in the output is desirable after compression. The total amplification in the channel amplifier is initially assumed to be 110 dbv. On the assumption that signals might be observed down in noise, compression is applied from -10 dbv and up, see Fig. 1.

Tentatively the use of d.c. amplifiers is disregarded in the initial design. It is assumed that basically three amplifying stages are needed, which means a total of five low-frequency cut-offs prior to the switching tube. In the discussion of the cell-amplifier the time constant value of each cut-off (for a resulting cut-off frequency of 2/3 cps) was set to approximately 0.6 seconds. The higher cut-off can be introduced at will, and except for the single cut-off already present in the cell-amplifier, no additional high-frequency cut-off will initially be introduced in the channel amplifier. Short recovery time is essential, and it is tentatively assumed that as long a recovery time as 10 seconds may be permissible at the input of the CRO. This would mean a trail, covering an appreciable part of the 360° arc on the screen of the CRO.

The basic circuit diagram is shown in Fig. 2 with the AGC circuits omitted. For signals 10 dbv down in noise the gain of this amplifier is the same as the finally obtained gain in the final, AGC controlled amplifier. For simplicity it is assumed that the same tube in Class A operation is used throughout the circuit, and the data of the tube may initially be considered similar to those of a conventional pentode, such as 6SJ7, operated in resistance coupling at high plate and screen grid voltages. Under these conditions the tentative values for the circuit components may be as follows: (R_1 in Fig. 2 is referred to as R_3 in the cell-amplifier write-up)

R_1:	1 megohm	C_1:	0.6 mf
R_2:	0.25 "	C_2:	0.6 mf
R_3:	1 "	C_3:	0.6 mf
R_4:	0.25 "		
R_5:	1 "		
R_6:	0.25 "		

A subminiature tube that would be useful in this application is CK5702/CK6C5CX (similar to 6AK5). The data for this tube as a Class A1 amplifier are as follows:

V_h = 6.3 volts
I_h = 0.2 amps
V_p = 180 volts
I_{sg} = 120 volts
I_p = 7.7 ma
I_{sg} = 2.4 ma
g_m = 5100 mhos
r_p = 0.69 megohm
R_c = 200 ohms

The signal levels will first be discussed assuming the AGC requirements non-existent. The required gain per stage, for equal gain per stage, is 68, which can be rather easily obtained. The minimum signal levels, or noise levels, on the three grids is then, approximately

3 μv 0.2 mv 15 mv

If the grid bias is -3 volts, and appreciable positive grid current is assumed to begin at -0.5 volt, the maximum peak signal levels for linear operation with plus on the first grid becomes, roughly,

0.5 mv 40 mv 2.5 v

For higher signal levels the third stage will overload. At approximately 40 mv input voltage to the amplifier the second stage will overload, while the first one overloads at the end of the input dynamic range. For still higher signal levels special protection devices are relied upon.

It therefore appears possible to use grid current limiters in all three stages to help limit the output voltage in the region of strong signals. Such an arrangement is impractical, however, in view of the fact that the grid voltages may be of either sign.

Before a more specific discussion is entered into, the difficulty due to the polarity of the signal should be discussed. Even if the signal on the first grid was always positive, following amplifiers would nevertheless have to handle both positive and negative voltages, due to the alternating nature of the transient response. This would mean that compression by, for example, grid limiting in the amplifying tubes, would become very difficult, for one tube limits on positive input pulses, while the next one does not limit because of the negative input pulse. Generally, conventional limiting is suitable only above the specified signal dynamic range, to prevent overloading. One way out of the difficulty is to give up the requirements on true phase response in the output, and rely upon two-way rectification between stages for proper operation. Solutions without rectification inside the amplifier will first be attempted.

One solution, suggested by Dr. Jones, makes use of rectification between stages, and external, diode limiters, contributing proper amplitude levels so that any desired response curve can be obtained by superposition. This suggestion will be given consideration later.

Before a discussion of different solutions to the problem entered into, it should be clearly understood that many solutions are possible, although only a few are indicated. It is not practical to go much further with the theoretical investigation, as the behavior of the required nonlinear circuits, and the final response curves due to consecutive compression and limiting, are so much easier obtained experimentally, and by parameter relationships, expressed by diagrams obtained from measured data. It is believed that experimental work would soon yield circuits superior to the ones shown, and it is felt that under all circumstances the final amplifier compression circuits will be made up of various elements from each one of the shown solutions, which represent ideas rather than engineering design.

2. Consecutive Limiting by Feedback Loops.

Initially, it is assumed that the radiation cell scans over target, hotter than the background, and that the output from the cell is a 0.1 seconds long, positive, bell-shaped curve. This pulse therefore appears as a negative pulse on the input to the channel amplifier. It then follows that controlled negative feedback, one loop for each even amplifying stage, is an acceptable solution, assuming that the broadening of the passband and associated change in transient response does not jeopardize the operation of the circuit. At extremely weak signals the amplifier has a narrow passband, yielding maximum signal-to-noise ratio, while at strong signal it has a wide passband, reducing the ill-effects of "ringing," but increasing the recovery time. If fixed networks with the bandwidth independent of the amount of feedback are inserted outside of the feedback loops, the influence by negative feedback on the overall bandwidth is reduced. The arrangement with one feedback loop per stage, and no amplification in the

feedback networks, eliminates the difficulty of instability, and provides the desirable AGC characteristic by having the three feedback networks come in smoothly at three specified points on the final response curve, Figure 1. To make possible the use of feedback loops on all stages and for any sign of the amplifier input pulse, a phase-shifter must be inserted in every feedback loop, or a balanced amplifier scheme used for obtaining the same response from a negative voltage as from a positive one. The requirement on polarity independence complicates the otherwise simple feedback loop solution.

A circuit for negative pulse operation is indicated in Fig. 3. Due to the fact that a cathode follower provides matching from a high impedance to a low impedance, its grid can be connected directly to the grid of the following tube, while its cathode is used as "ground" end for the amplifier tube grid resistor R_g. As a circuit diagram only serves to show the principle involved, bias batteries have been inserted to symbolize proper electrode voltage sources. The maximum voltage gain in the cathode follower is approximately one, and as the only reactive element in the feedback loop is the grid capacitor for the following amplifier, no difficulties with instability are to be expected. For general use, when the polarity of the incoming voltage could be of either sign, the required phase shifter may have the form of a phase reversing tube of gain 1 and a second cathode follower. Here d.c. amplification may be used so as to avoid the undesirable phase shift and time delay in an additional RC network. The other specific solution here considered is a phase-reversal circuit in the very input of the channel amplifier, so that, in effect, two independent channel amplifiers result, one for each polarity of the input signal voltage. With this arrangement, all voltages are compressed in all stages, independent of sign. If so is required, rectification may be added in the channel amplifier output.

The cathode follower is normally biased in the region of cut-off. When the output voltage from the amplifier stage exceeds the value designating the delay period, plate current will start to flow and then increase in accordance with the dynamic characteristic for the tube. With proper choice of component values this provides a gradual increase in the cathode follower amplification (< 1), and thus in the feedback factor. This increase can be properly controlled if a constant, small direct current is maintained through the cathode resistor, see Fig. 3. Thus negative feedback is obtained that increases with the signal level, providing a characteristic that can be adjusted to become similar to the desired AGC characteristic.

The curve in Fig. 1 actually requires AGC from the weakest signals encountered, 10 db down in noise. For this the highest signals encountered is that at the output of the third tube, and one control loop circuit in accordance with Fig. 3 may be inserted here to handle the main part of the first 20 db, or so, of dynamic range. This means input signals from 3/3.16 or approximately 1 micro volt, to 3·3.16, or approximately 10 micro volts, and total amplifier outputs of from 1 x 316000 = 0.316 volts to 1.0 volts. The initial output voltage of 0.316 volts appears to be just sufficient to operate the circuit in Fig. 3, but it should be noted that the actual, non-signal voltage that appears on the output terminals is set by noise,

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for 3 μv input, and is 0.56 volts. The proper scale factor 1:2 is secured by proper choice of the initial Q-point and by adjustment of the resistor R_5, the potentiometer P, and the steady direct current through P. When the signal level becomes larger, the Q-point slides from the bottom bend of the characteristic towards the linear part, and after this the amount of negative feedback action tends to become constant and may be superimposed on additional feedback action, now introduced in the earlier part of the amplifier to handle the initial region of the 1:6 dbv range. This additional feedback action may be obtained from another circuit of the form shown in Fig. 3, across the second amplifier stage, and later, at still higher input signal level, from a third circuit of the form shown in Fig. 3, arranged across the first amplifier stage. Thus, for the main and upper part of the DAGC characteristic all the circuits are active, still there are no connections from end to end of the amplifier, jeopardizing the stability.

Part of the upper dynamic range may be handled by a limiter, following the third amplifier stage. This limiter should operate on positive as well as negative pulses, and may be made to serve outside of the 140 dbv range, associated with "sun-protection" type circuits.

To facilitate the choice of component values for the cathode follower circuits, the AGC curves for gain and output voltage have been plotted with linear scales in Fig. 5. Substitute curves have been used to provide a smooth transition from the 1:2 db range to the 1:6 db range. The most attractive solution here is by means of diode limiters or clippers, but a different, possible arrangement, utilizing a phase reversing cathode feed arrangement is shown in Fig. 4.

The circuit in Fig. 3 does not require any polarizing potential that cannot be provided by well-known tube-circuit techniques. As a cathode follower is essentially a linear device, operation must commence at or beyond cut-off, so that the cathode follower amplification, or transmission constant of the feedback network, varies from a fraction of 1 percent to 20 percent, or so. This can be achieved in practice, and corresponds to an amplifier stage gain variation from 68, or so, down to approximately a ten times lower value. The achievement of the final gain value for the entire amplifier does not present too serious a problem, for already at the cross-over point the output voltage from the second stage is sufficient to contribute to gain reduction in the second stage, and for a still larger amplifier input voltage the first stage will also become active and contribute to the overall gain reduction. Further, circuits as the one shown in Fig. 4 will take care of the upper part of the characteristic, and it is therefore safe to assume that calculation and experimental checks should be centered on the weak-signal behavior of the control circuits.

Estimation of gain reduction with a cathode follower feedback loop on the third stage seems to indicate that it is possible to produce the required rate of change of gain at very weak signals. A check has been made of the rate of change of the stage gain that can be obtained when a conventional tube operates under most favorable conditions. This check proves that the desired overall compression can be obtained, and that if some wiggles around the curve shown in Fig. 1 are permissible, a satisfactory consecutive action of the three cathode follower loop circuits obtains. In practice the "set-in" points for the three circuits must be adjusted with an output meter until a smooth final curve is obtained.

The use of cathode follower loops may introduce some difficulties in maintaining desired transient response. If balanced amplifier stages are used, and the rectified, total outputs combined, sufficient symmetry is believed obtainable to justify the complications of the circuits. If an unbalanced scheme is used, with only one amplifying channel and a phase shifter prior to each cathode follower, as is indicated in Fig. 3, symmetry for both polarities of the signal is also obtainable; it is believed to the degree needed. Both the balanced and unbalanced scheme looses symmetry under conditions of overloading. It is necessary that the two circuits are set up in bread-board form, and experimental values obtained, before any definite conclusions regarding the usefulness of the feedback loop AGC solution are drawn.

3. Consecutive Limiting by Diode Pairs.

The simplest solution of the AGC problem would be to utilize the limiting characteristics of the amplifying tubes themselves. For positive signals on the grid, a smooth and adjustable compression is obtainable by means of grid currents through the grid resistor and associated resistors, and several tubes may be made to add to the overall attenuation in such a way that the desirable overall response is obtained. To secure compression from the weakest signal 10 dbv down in noise, use must be made of at least one grid circuit following the third tube, from which the minimum output voltage is 0.316 volts. Additional compression is obtainable by the use of the plate current-grid voltage characteristic and the cut-off region of the tubes, but this solution may not be attractive, as the greatest rate of change of the tube gain obtains towards the end of the dynamic range, and beyond this point, for fixed bias, the regulation comes to a stop for zero plate current, unless variable-mu tubes are used. Another means for compression is to operate the amplifying tubes at very low direct voltage on the plate, so that for increasing positive voltage on the grid the output of the tube becomes limited. While all these regulation possibilities lend themselves better to clipping than to smooth AGC, it is likely that the desired, final response can be obtained, assuming not less than three amplifying tubes being used. Corrections of the compression curves can be obtained by special component values and proper arrangements of the screen-grid circuits. By the use of multi-element tubes, such as heptodes, additional control features can be secured.

The difficulty in all these schemes utilizing the tubes themselves as control element is the fact that the channel amplifier is supposed to work the same way for both polarities at the input terminals. Thus, while for a certain signal amplitude there would be no limiting in the first stage, and a total gain of, say 40000, the opposite polarity on the amplifier input may yield no limiting on the first stage, good limiting on the second stage, and no limiting on the third stage, and a total gain of, say, 100000.

One solution to the above problem is to design the amplifier stages so richly, that within the dynamic voltage ranges on the tube electrodes the compression is negligible. All the desired compression is then obtained from two-way diode attenuation networks between the tubes, and after the last, or third tube. Fig. 6 shows the principle for this arrangement, including only the last two tubes in the amplifier. It follows that for very weak signals the diodes operate as linear rather than nonlinear elements, and both half cycles of an a.c. signal applied to the amplifier pass through. Rectification sets in at the point where the amplitude has reached sufficiently high value, and it follows that this point of commencing, limiting action moves towards the input end of the amplifier as the input amplitude increases. This means that more and more compression circuits become active, and for strong signals, at the upper end of the final dynamic characteristic, all compression circuits are active, while the amplifying tubes still operate approximately linearly. More than one diode-pair may be used with associated network as is shown at the output end of the amplifier.

The diode compression method does not require any additional coupling capacitors, nor does it introduce serious problems with regard to transients and recovery time. The resistors $R_4R_5R_6$, $R_9R_{10}R_{11}$, $R_{12}R_{13}R_{14}$, and others have screw-driver adjustments so that the overall compression curve can be adjusted whenever so is required. The electrode voltages are obtained from a separate rectifier, or partly from drop resistors in the leads of the amplifying tubes. As diode-pairs an equivalent sub-miniature type to 6H6 may be used, to the extent presently available.

Note the possibility, pointed out by Dr. Jones, of replacing $R_{10}R_{11}$ and similar units by just one resistor, also of using nonlinear <u>series</u> elements.

The diode compression circuit and the cathode follower feedback circuit yield a combination of interest, in which the diodes not only act as part of an attenuating network, but also provide feedback loops. The principle of this arrangement is shown in Fig. 7. The right part of this circuit may be considered identical with that of the plate side of the last amplifying stage in Fig. 6, but the left part is different. The ground ends of the diodes are connected to serious resistors, providing part of the grid resistor for the amplifying tube. When the incoming signals are very weak, the diodes do not conduct, and the circuit operates just as ordinary amplifier stage without compression. When the input amplitude increases, say in positive direction, the diode D_1 will start to conduct

and a bucking voltage will appear across the resistor R_1, so that negative feedback action obtains. At the same time there will be a voltage drop across the resistor R_6. Compression therefore obtains both for reasons of negative feedback and for reason of diode network attenuation. When the compression becomes extensive, the input voltage will start to feed an appreciable voltage component on the cathode of the diode, so as to slightly increase the conductivity of the diode. All these actions can be blended together to give the desired shape of the compression characteristic for both positive and negative input voltages. The required diode bias can in the case of D_1 be obtained by returning the resistor R_1 to a point X on the cathode resistor R_{10}, while for D_2 a different source of bias voltage is required.

The diodes are heated from a proper filament transformer. Due to the low signal frequency, and reasonable resistance values, no particular difficulty is expected to arise from the arrangement of the filament heater circuits.

If so is desired a second pair of diodes can be added with associated attenuation and feedback networks, so that more freedom and flexibility in adjusting the resulting compression characteristic obtains. Another means for more flexibility in adjustment is to connect a shunting diode A in series with a resistor across the diode D_1 and resistor R_1. (Similarly another diode B across the diode D_2 and resistor R_2). This arrangement is shown in principle in Fig. 7 and in detail in Fig. 8. If by choice of proper bias the shunting diode A is made to pass an appreciable current in the same direction from the resistor R_6 as D_1, the result will be an increase in the attenuation of the signal via R_6, but a decrease in the attenuation, caused within the proper signal interval by the feedback voltage and feedback action, which will change the character of the compression curve.

4. Use of Output Nonlinear Network

The solution suggested by Dr. Jones makes use of resistance networks and diodes, one combination for each amplifying stage. The signal is attenuated in stages, so that the diodes are excited in steps, and enter into action in a sequence that will give the desired response. While the initial part of the total output is contributed by the last amplifier stage, the maximum output is contributed by all three stages, in proper parts. The principle of this circuit is shown in Fig. 9.

With reference to all the above solutions the use of germanium diodes may be considered at the side of tube diodes. The former do not require any heating source, but may require a thermostat to reduce the effect of temperature dependence. The latter require a heating source but do not require a thermostat.

One nonlinear element not previously mentioned is the "varistor" from Bell Telephone Laboratories. This unit replaces a diode pair and is of very small dimensions. Serious consideration of the varistor solution is recommended.

HS/h

Channel Amplifier

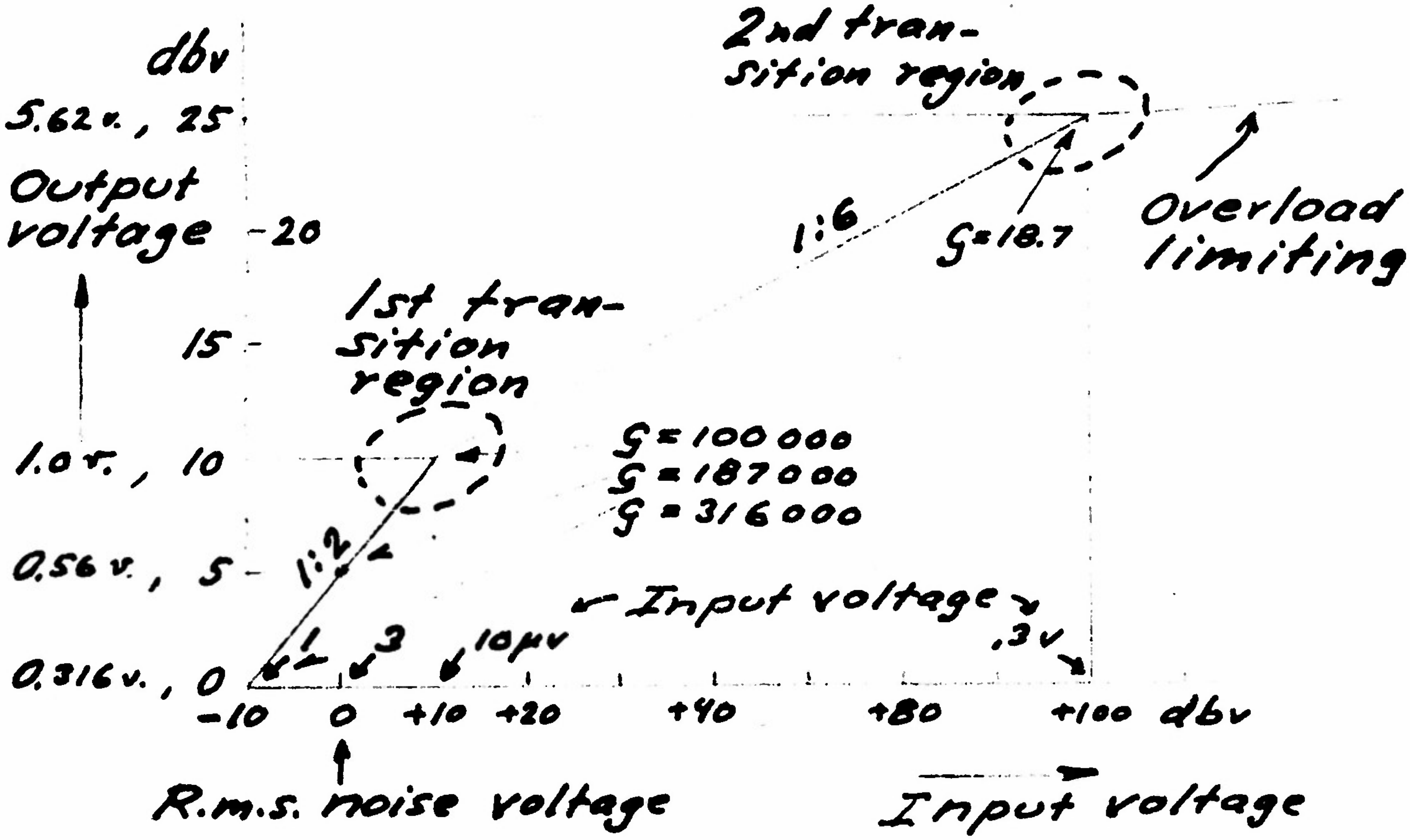

Fig. 1

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Channel Amplifier

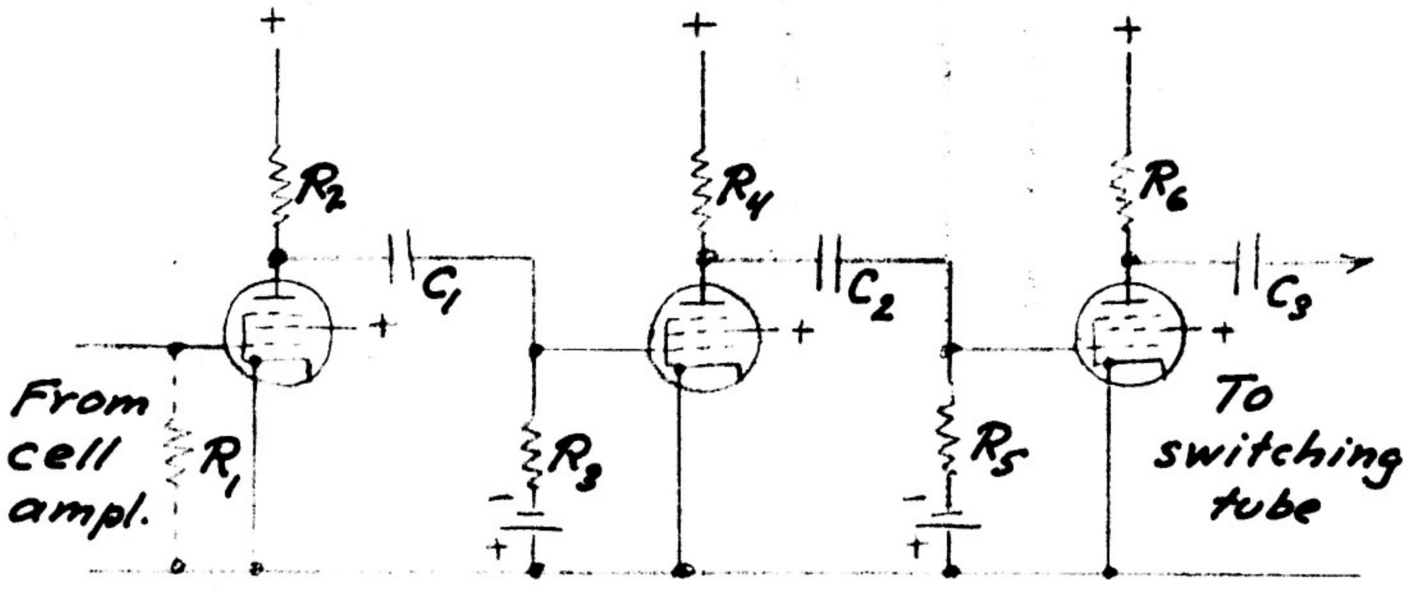

Fig. 2

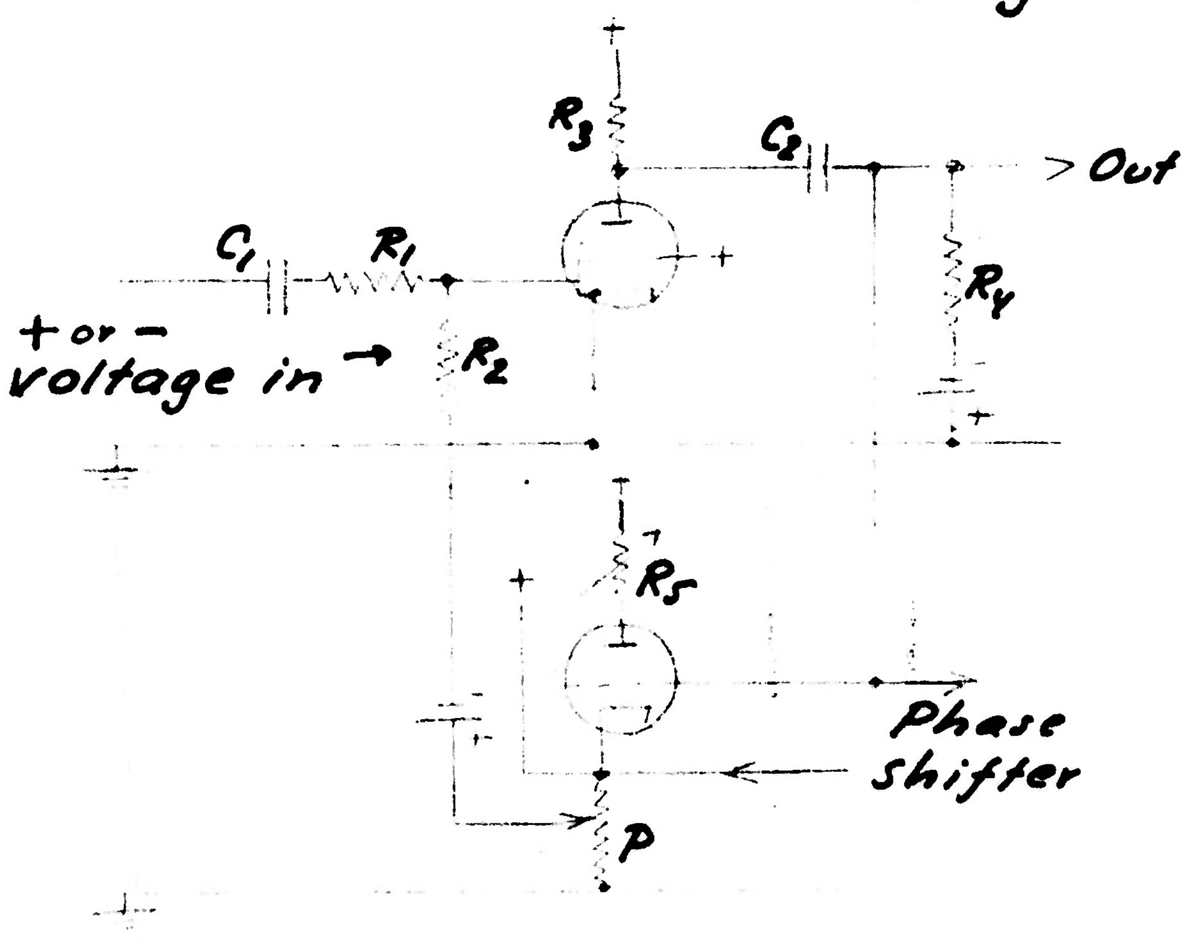

Fig. 3

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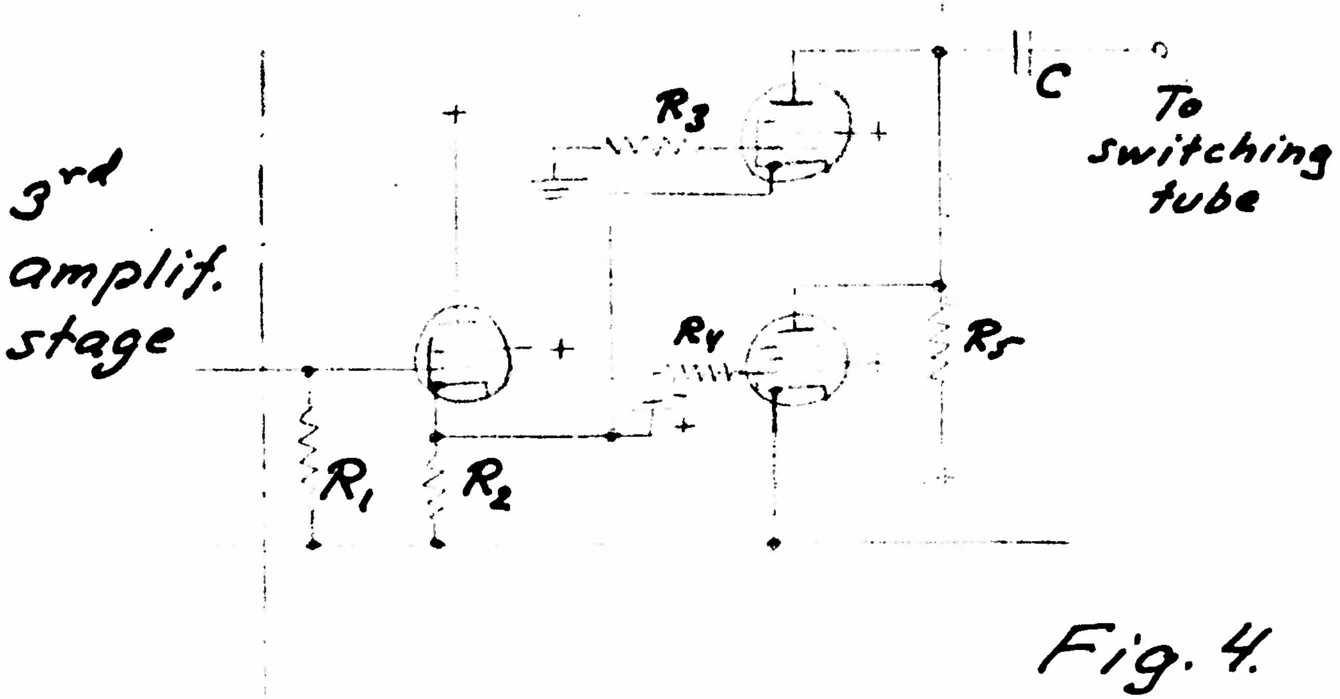

Fig. 4.

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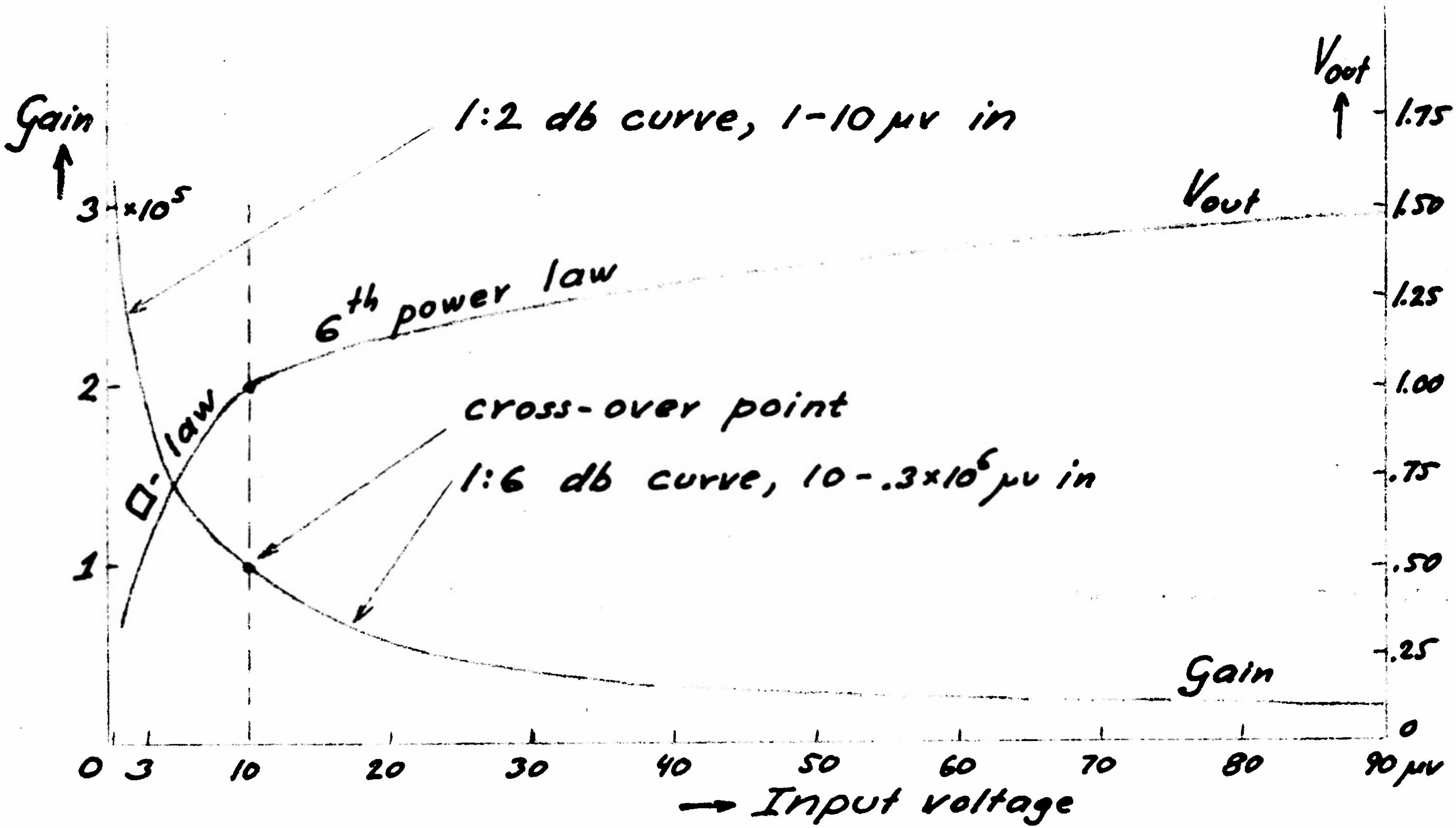

Fig. 5

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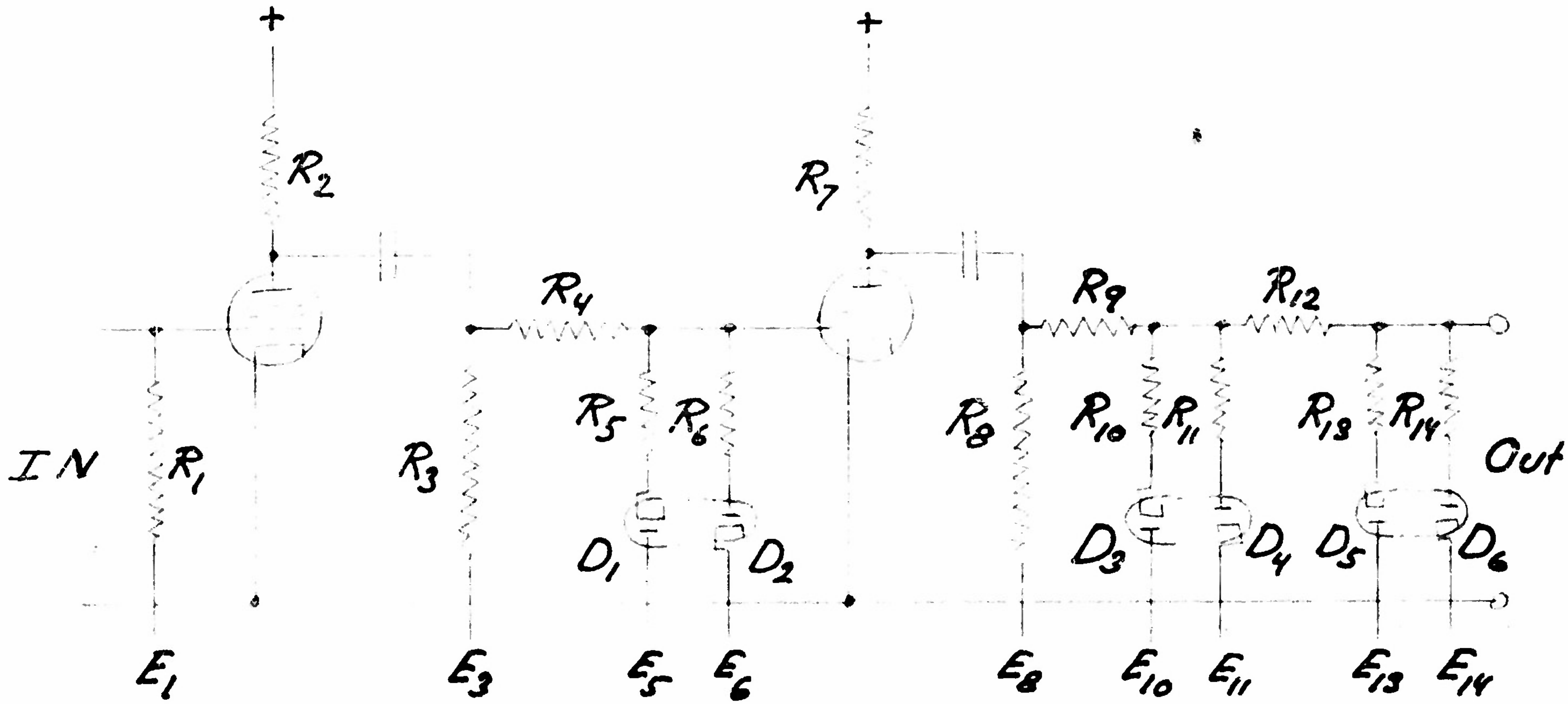

Fig. 6

3 Jan. 1949
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Channel Amplifier

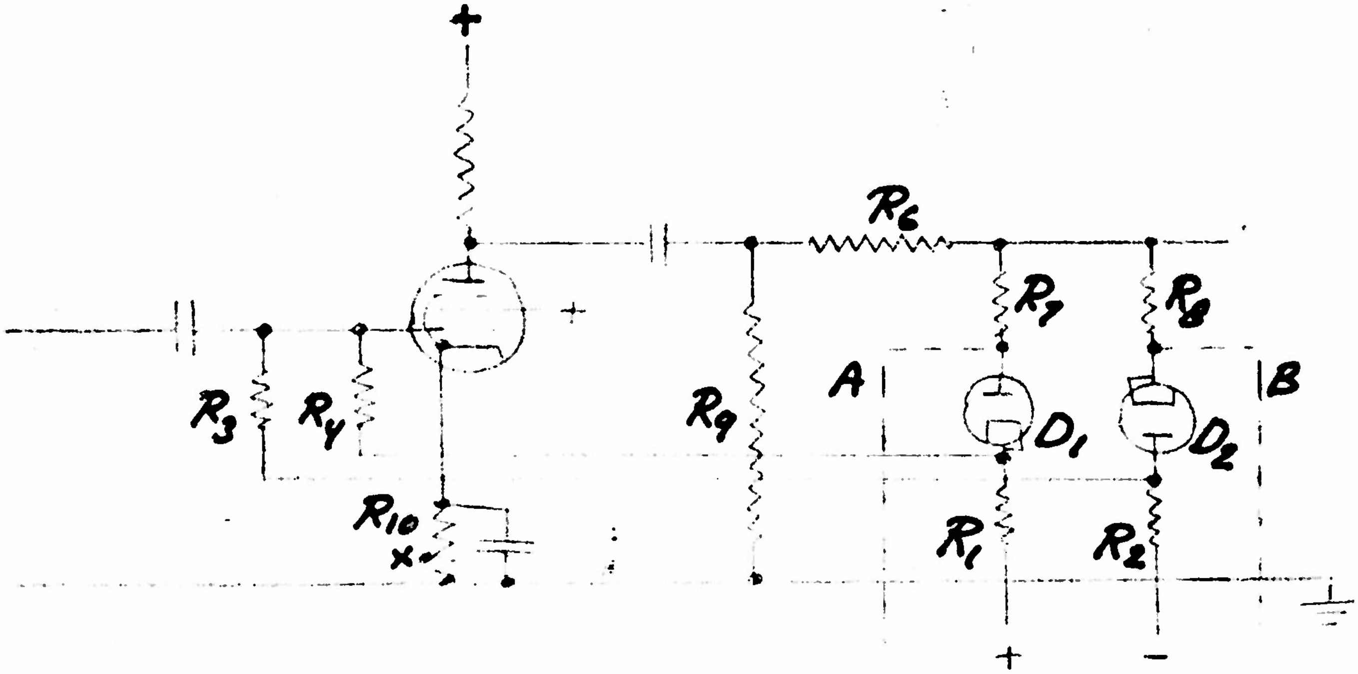

Fig. 7

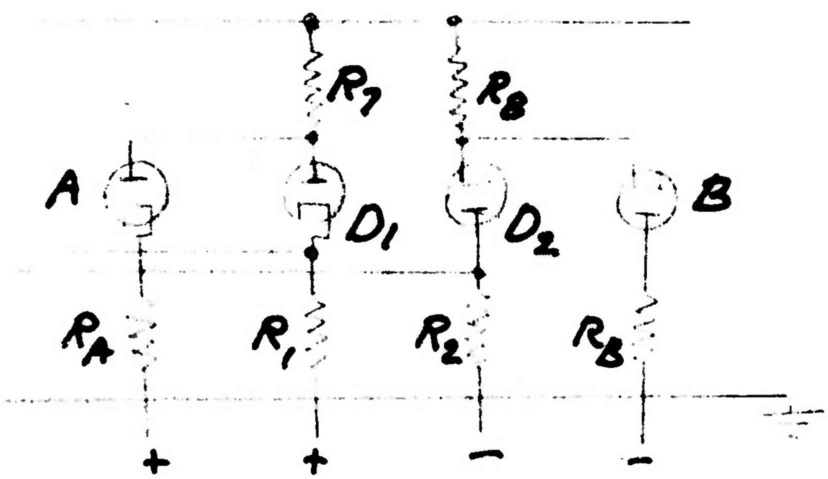

Fig. 8

Jan. 7, 1949
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4N

Channel Amplifier

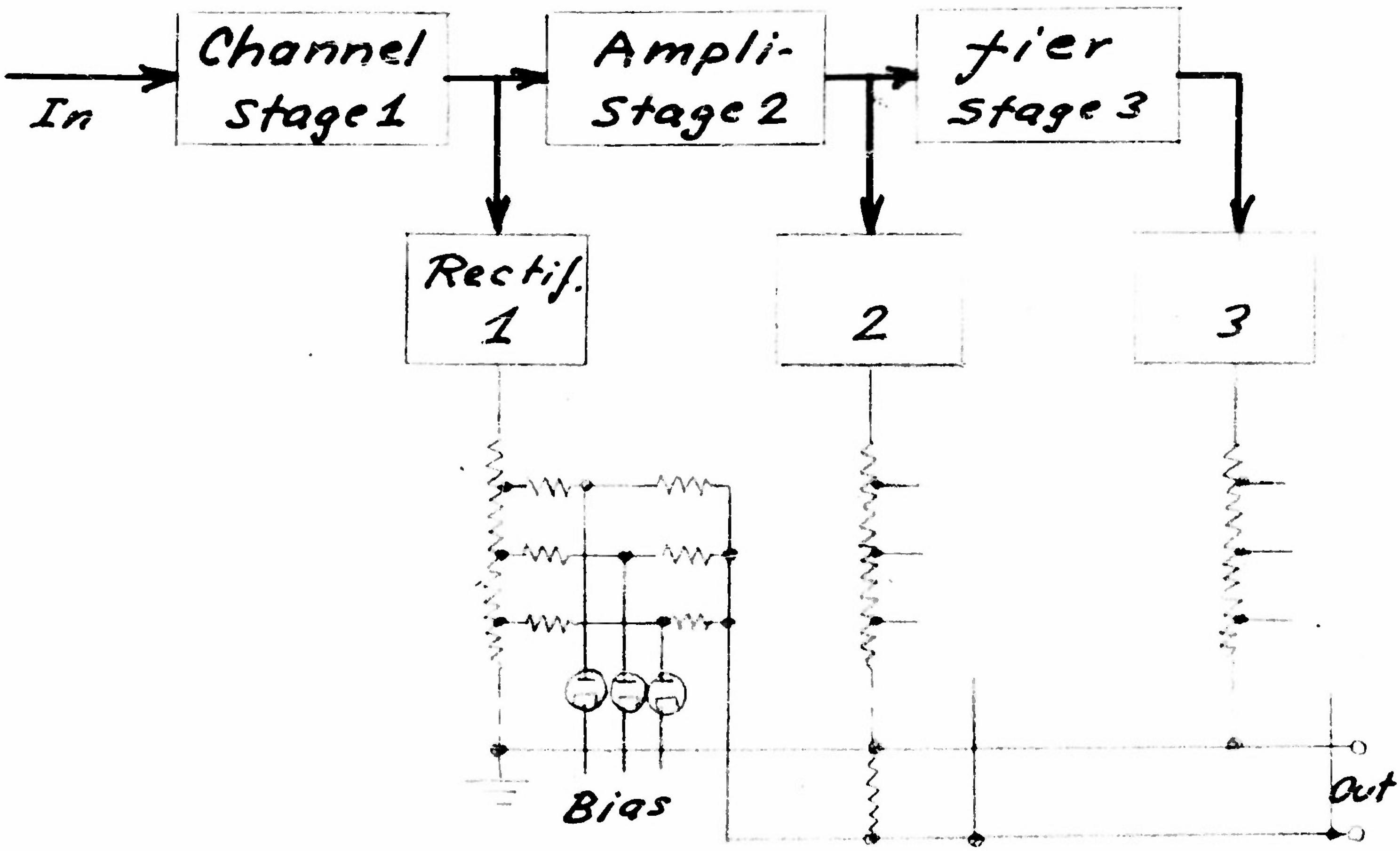

Fig. 9

Jan. 10, 1949
J. Stahman

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